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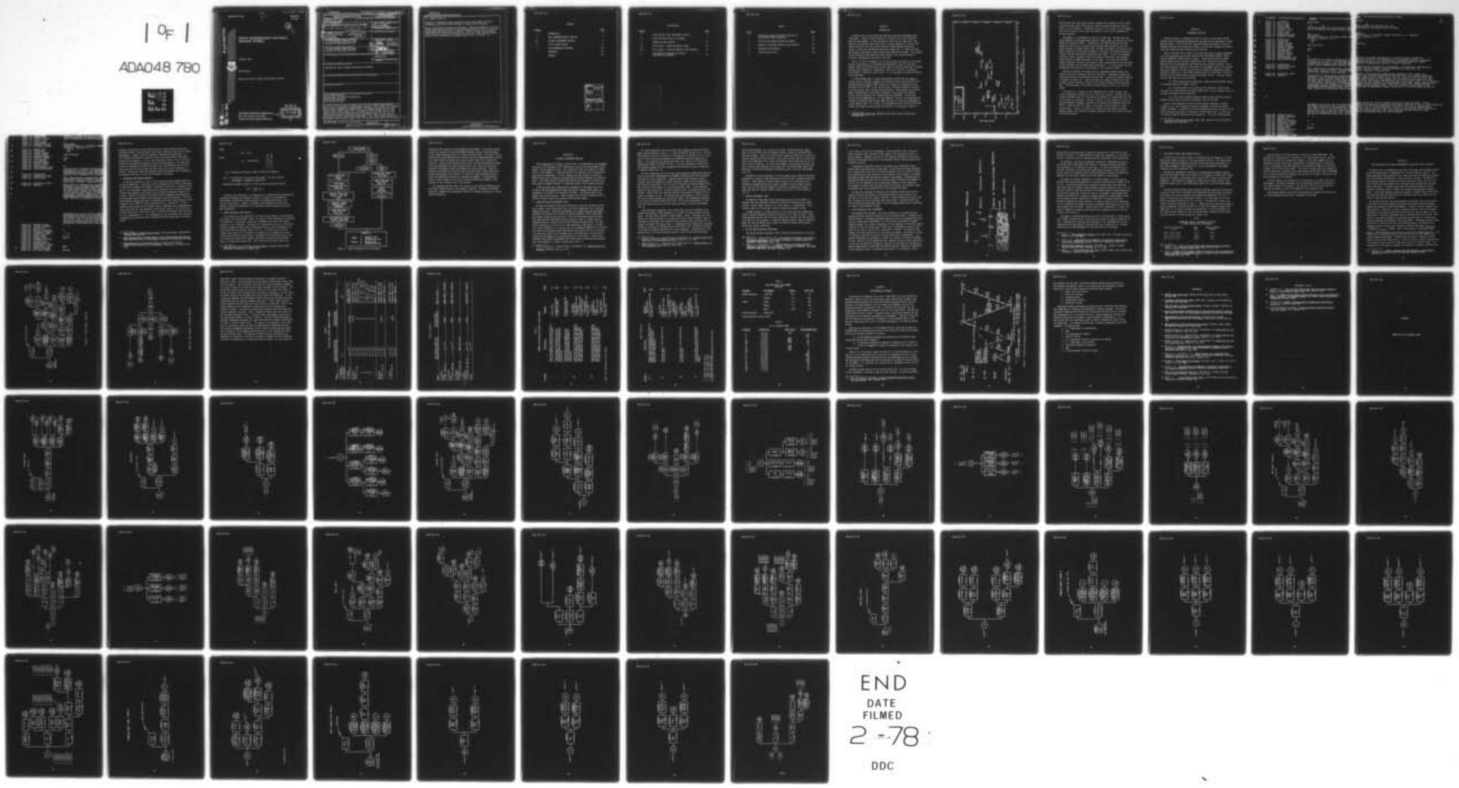

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SAFETY METHODOLOGY FOR SPACE NUCLEAR SYSTEMS

October 1977

Final Report

Approved for public release; distribution unlimited

AIR FORCE WEAPONS LABORATORY
Air Force Systems Command
Kirtland Air Force Base, NM 87117

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number) (UNCLASSIFIED ABSTRACT)

Radioisotopic Thermoelectric/Thermodynamic Generator (RTG) systems are frequently used to power Department of Defense (DOD) and National Aeronautics and Space Administration (NASA) satellites. The launch of RTGs dictates that the user agency assure the Interagency Nuclear Safety Review Panel that risks to the populace are minimal and exposures below acceptable levels for any logically conceivable accident scenario and environment. Each agency (Energy Research & Development Administration (ERDA), NASA, and the DOD) participating on the panel over

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20. Abstract (Cont'd)

performs an independent safety evaluation of the system under review and recommends action for the RTG Contractor's Safety Analysis Report.

Typical techniques and results are discussed. Particular attention is paid to the analyses and test results for the Multihundred Watt RTG used in the Lincoln Experimental Satellites 8 and 9 (LES 8/9). Specific details of the nuclear safety analysis of the LES 8/9 mission are set forth. Other analysis methods used and future methodology development goals are also discussed.

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SECTION I

INTRODUCTION

Since the early fifties there has been one continuous requirement about space power: Larger and larger amounts of reliable, long lived electrical power has been needed. It has been equally clear that to supply this large quantity of electrical power only solar or nuclear systems will suffice; the weight associated with the various chemical systems becomes prohibitive. Figure 1, taken from the DOD/AEC Space Power Study (ref. 1), shows the solar and nuclear space electric power history from 1960 to the present. For students of the history of space power and space missions, this study provides an excellent, comprehensive overview of the area.

Now, it is not the purpose of this study to argue the merits of solar power versus nuclear power or to delineate the advantages of one over the other. However, there are missions where nuclear power is required--deep space launches, missions where elements of concealment or ability to function in anomalous environments is important, come to mind. It is this type of mission with which we are concerned.

In the mid-1960s when it became increasingly evident that the amount of nuclear material needed to generate the electrical power would be nontrivial--the Mariner-Jupiter Saturn (MJS) mission will involve the launching of over 220,000 curies of PU^{238}--it was realized that a thorough systematic review of all space nuclear power launches would be needed. Safety aspects and environmental considerations are of major importance; the structures of national policy, test ban treaties for instance, must be considered. The National Security Action Memorandum No. 50, 1965 (NASM 50), revised, indicated that the concept of launching space nuclear power missions was receiving consideration at the highest level. As a result, the Interagency Nuclear Safety Review Panel (INSRP) was formed with the charter and direction to thoroughly review all

1. DOD/AEC Space Power Study, DOD/AEC AD HOC Study Group on Space Power, 30 June 1974.

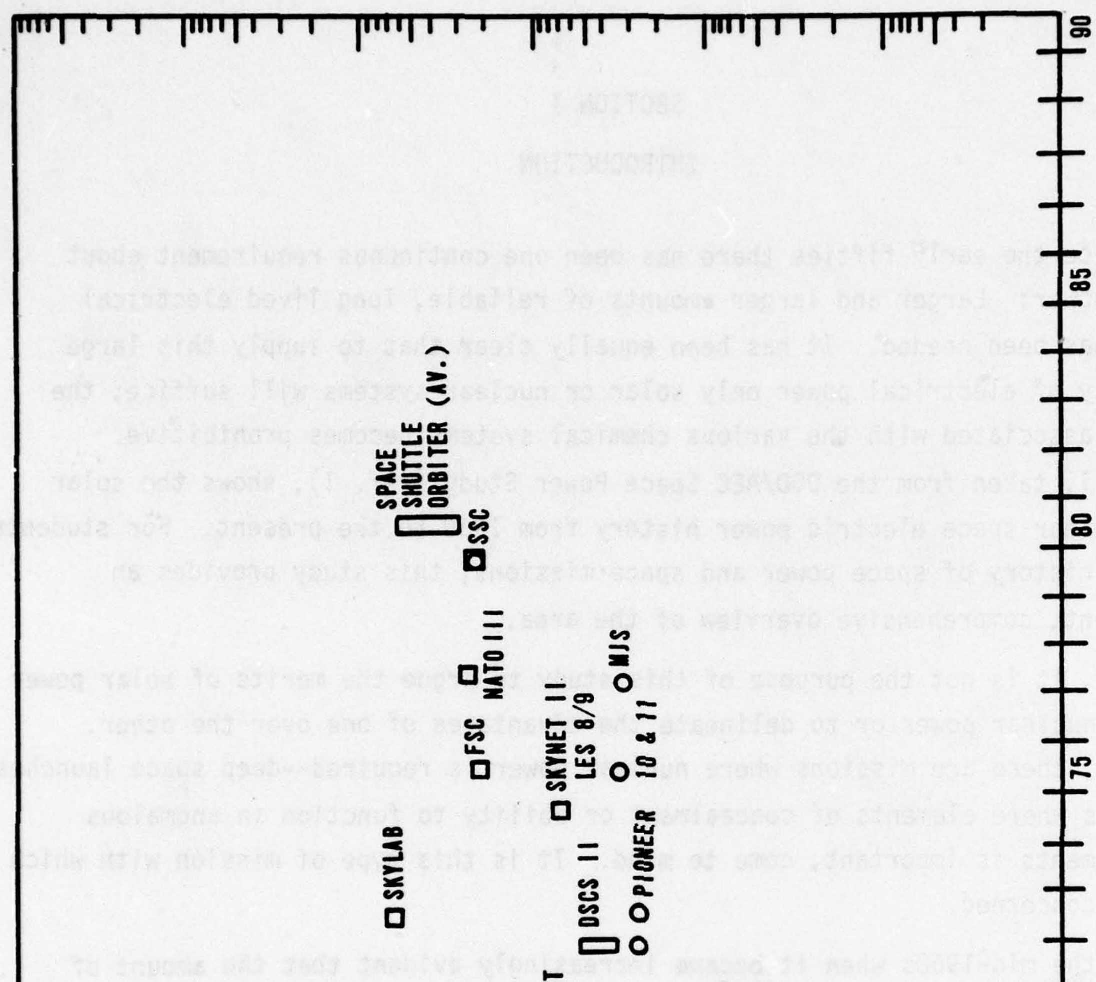

Figure 1. Space Electric Power Requirement History

United States (US) space nuclear power launches and to prepare a formal Safety Evaluation Report (SER) which would be staffed through the National Security Council of the President. Presidential approval of the launch, or lack thereof, would then be based on this safety evaluation, as well as the constraints of national security.

The members, or coordinators as they are called, are: One each from the Energy Research & Development Administration (ERDA), NASA, and the DOD with their respective supporting staffs. Traditionally, the ERDA coordinator has been named from the Division of Space Nuclear Systems (SNS) now the Division of Nuclear Research and Applications (NRA); the NASA coordinator from the Office of Center Operations, and the DOD coordinator, selected by the Deputy Secretary of Defense, from the Directorate of Nuclear Surety (DNS). The Air Force Weapons Laboratory (AFWL), persuant to AFR 122-15 and 16, functions as the technical support team to the DOD coordinator on the INSRP. It is thus that the AFWL became intimately involved in the nuclear safety review process for all US space nuclear launches, even the NASA space explorations. It is this support and the methodology involved which is the subject of this technical report.

Section II contains a discussion of the independent safety analysis provided by the AFWL in support of the DOD coordinator. Mathematical models are emphasized and analysis techniques are described. Accident environment modeling is covered in section III. Launch pad abort and reentry situations are highlighted; special attention is given to the relation between theory and experiment. The limitations of the safety analyses testing, to date, are also discussed.

In section IV, a summary of the independent AFWL nuclear review of the Lincoln Experimental Satellites 8 and 9 (LES 8/9) is given. Excerpts from the accident sequence trees for this mission and probability summary tables for the launch phases are presented. Section V presents a brief overview of the role the Environmental Statement, required by the National Environmental Policy Act (NEPA) of 1969 and AFR 19-2, plays in the safety review process for these mission types. Finally, included as an appendix are the complete accident sequence trees, with probability numbers, generated during the safety review of the LES 8/9 mission.

SECTION II

INDEPENDENT ANALYSES

The AFWL provides an independent safety evaluation of each space nuclear system as well as continuous evaluation of the power source contractor's safety analysis report. Each of the other responsible agencies performs its own independent analyses and evaluations; however, only the AFWL analyses and system contractor safety analysis techniques are discussed.

Several different basic analysis tools have been used to prepare representative risk assessments on the power sources--most often Radioisotopic Thermoelectric Generators (RTG)--prior to launch. These analyses must be comprehensive enough to give realistic probabilities for launch pad and reentry anomalies plus the consequences associated with any credible accident. Due to the vastly different natures of the series of environments the RTG fuel containment must withstand, the analysis used must be capable of adequately treating sequential events (e.g., fuel sphere assembly impact at velocities in excess of 200 fps with or without reentry heating and thermal stress). The basic safety analysis utilizes one of the following:

(1) Matrix descriptions showing basic system state transitions caused by accidents (used for Pioneers F and G).

(2) A modified Monte Carlo analysis which generates accident probabilities from Failure Modes and Effects (FMEA) data, a basic sequence tree, and accident environment failure threshold.

(3) Fault Trees (accident sequence trees) showing detailed accident sequencing with nominal accident consequences (LES 8/9 and MJS).

Each of these techniques requires either separate treatment of system response (i.e., fuel releases) or separate treatments of launch pad and/or reentry accidents. To date the only solid documented data base available to the safety analysis contractors is the Overall Safety Manual (ref. 2), which was initiated by ERDA and prepared by NUS Corporation. This four volume document

2. The Overall Safety Manual (OSM), USAEC (SNS), prepared by NUS Corporation, Rockville, MD., June 1974.

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provides a sound basis for the preparation of a safety analysis report and exceptional detail on the biological dose paths, inhalation codes, and ultimate consequences. However, the basic approach to generating source terms; i.e., fuel releases associated with specific missile and radioisotopic heat source accidents and responses, is left to the innovative devices of the civilian contractor and the technical analysts for the reviewing agencies. The remaining discussion highlights the transition matrix and the modified Monte Carlo techniques and specifically discusses the AFWL event tree analysis prepared for LES 8/9. The typical event tree technique shows the complexities of sequential environments that must, in some unified manner, be analyzed.

1. TRANSITION STATE MATRIX ANALYSIS

To date this technique, as well as the others discussed, depends heavily on the missile FMEA data. This type of data is prepared by the missile contractors to show failure probabilities based on component failure data. Therefore, to be used in risk assessment, these data must be translated into realistic accidents in the launch sequence and related to the ultimate environments created in an accident. Models for accident environments and RTG responses are developed in the RTG Safety Analysis Report (SAR) provided by the RTG contractor. The transition matrix technique was used in conjunction with event tree analysis for the Pioneers F and G, SNAP 19, safety evaluation (refs. 3 through 5). In this method the heat source and its internal modular components were represented by a state vector defining the probability that the heat source is in a particular discrete state (e.g., heat source intact, internal fuel spheres intact but free, or fully released) (ref. 4). The consequences of any environment were nominally represented by a new state vector characterizing the changed state of the heat source.

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3. SNAP 19/Pioneer F Safety Analysis Report, Teledyne Isotopes, INSD-2873-42, Timonium, MD, June 1971.
4. Nuclear Safety Analysis Methodologies for RTG Equipped Satellite Launches, MDAC, AFWL-TR-76-166, Air Force Weapons Laboratory, Kirtland AFB, NM, 1976.
5. Methodology Study for Preorbital Aborts, Teledyne Energy Systems, AFWL-TR-76-223 (Revised), Air Force Weapons Laboratory, Kirtland AFB, NM, 1976.

where

$$S^{i+1} = M^i S^i$$

where

$$S^k = \text{State Vector} \begin{bmatrix} P_1^k \\ P_2^k \\ P_3^k \\ \vdots \end{bmatrix}$$

P_j^k = Probability of being in state j before environment k

$M^i_{j \leftarrow j'}$ = Probability of transition from stage j' to state j during environment i (elements of matrix M^i)

Sequential accidents leading to a final state are treated as follows:

$$S^{I+1} = \prod_{i=1,I} M^i S^i$$

In theory, this technique is an adequate way of characterizing the sequential accident environments and responses; however, in practice with sequential environments, the matrices become unwieldy with elements described by probability distributions. However, the method, when combined with event tree analysis, proved an effective tool for describing discrete system and environment transitions.

2. LAUNCH PAD MONTE CARLO ANALYSIS

This analysis tool was effectively utilized for the Vikings A and B analysis which again utilized the SNAP 19 RTG. The results of this technique are published in reference 6. The method is described in somewhat more detail here than is available in the literature. The Monte Carlo technique was used as a simulation process to compute 10,000 histories developed through an event/consequence flow chart describing the accident process (fig. 2). In each history the radioisotopic heat source unit is exposed to a sequence of environments with associated system response probabilities. The Monte Carlo simulation was also used to calculate the convolution integrals describing interfacing distributional events in system state transitions. This allows the new system state to be

6. SNAP 19/Viking '75 Final Safety Analysis Report, Teledyne Energy Systems, ESD-3069-15, Timonium, MD., August 1974.

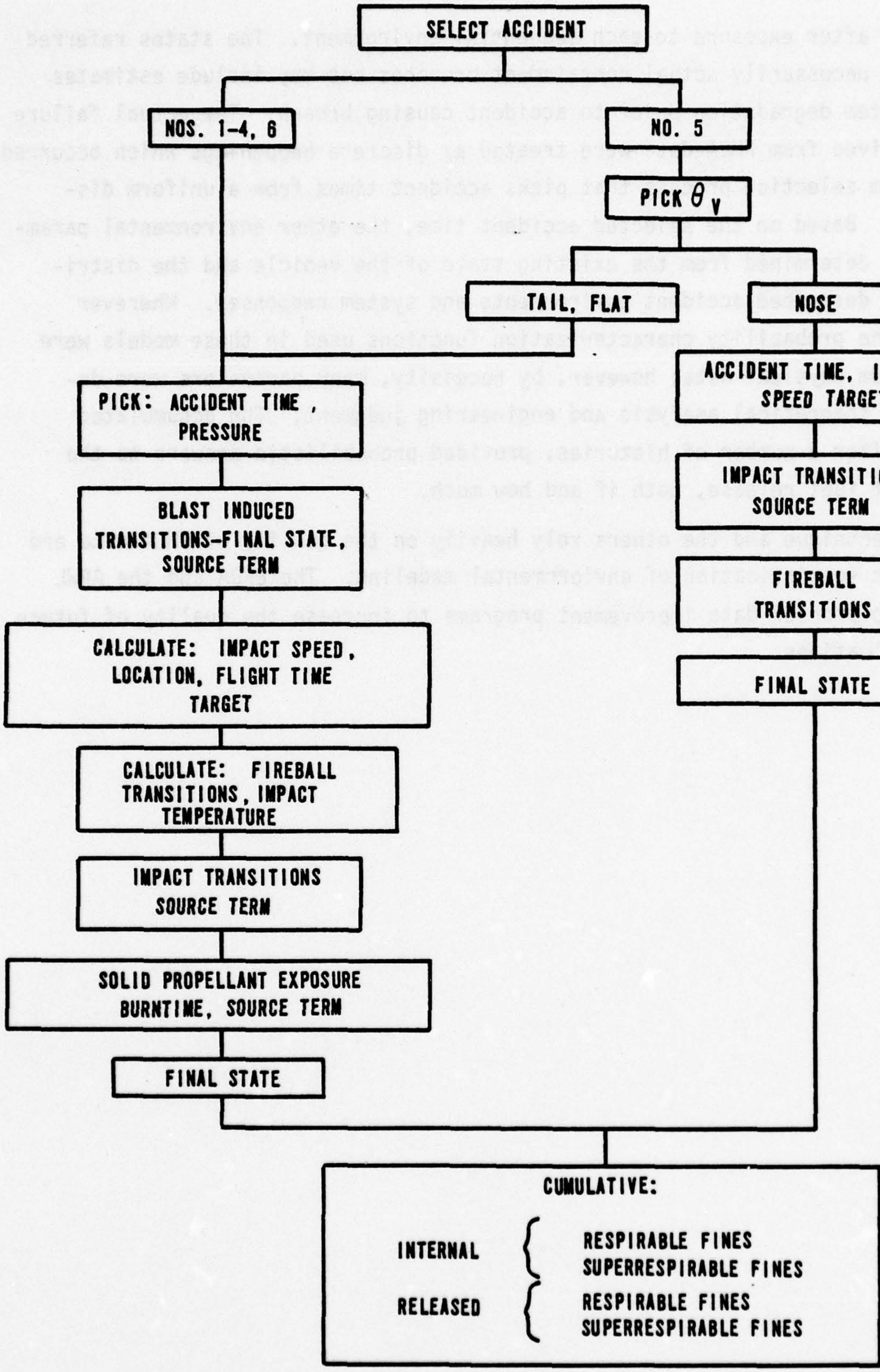

Figure 2. Launch Pad Monte Carlo Flow Diagram

determined after exposure to each sequential environment. The states referred to are not necessarily actual containment breaches but may include estimates of the system degradation prior to accident causing breach. The actual failure events derived from FMEA data were treated as discrete happenings which occurred as a random selection process that picks accident times from a uniform distribution. Based on the selected accident time, the other environmental parameters were determined from the existing state of the vehicle and the distributionally described accident environments and system responses. Wherever possible the probability characterization functions used in these models were derived from physical data; however, by necessity, many parameters were derived from theoretical analysis and engineering judgment. The accumulated results, after a number of histories, provided probabilistic answers to the question of fuel release, both if and how much.

This technique and the others rely heavily on the quality of FMEA data and the current sophistication of enviornmental modeling. The ERDA and the AFWL continue to sponsor data improvement programs to increase the quality of future safety evaluations.

SECTION III

ACCIDENT ENVIRONMENT MODELING

The consequences of accidents involving RTG are determined by the estimated response of the radioactive fuel containment to the accident environment (blast, impact, liquid propellant fires, solid propellant fires, and reentry) or combination of environments. To help characterize the response, data on the environments must be accumulated. To date, emphasis has been placed on simulating defined "worst case" accidents and evaluating the system response on a pass/fail basis. The safety analysis process then applied the responses to various accident scenarios deemed "probable" to determine possible fuel release situations.

Tests that have been conducted have attempted to investigate the survivability of the Multihundred Watt (MHW) Heat Source Assembly (HSA) and/or its components in the event of catastrophic accidents. The MHW was used in the Voyager and LES 8/9 missions. These accidents are basically divided into two areas of concern--launch pad accidents and unplanned reentry.

1. LAUNCH PAD ABORT ENVIRONMENTS TESTS

Accident environments that would characterize launch pad accidents include blast, impact, liquid propellant fires, and solid propellant fires, including sequential exposure. The blast environment (S-1) safety test was performed to determine the survivability of MHW Fuel Sphere Assemblies (ESA) in the blast environment created by the explosion in the Titan transtage propellant tanks. This explosion was simulated by placing a group of FSAs in a shock tube and subjecting them to a shock wave with the following characteristics: (a) peak static overpressure of 57 psi; (b) a peak stagnation overpressure of 133 psi; (c) a static impulse of 1.31 psi-sec; and (d) a stagnation impulse of 3.2 psi-sec. This shock wave simulated those overpressures that would occur for a 5 percent TNT equivalent yield of the transtage, which was determined to be more than 10 times the yield expected in the vast majority of Titan aborts. The fuel containments (Post Impact Containment Shell; PICS) were not breached and evidenced very little damage as a result of these tests (ref. 7).

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7. General Electric Co., Space Division, Philadelphia, PA, Safety Test No. S-1, Explosion, GEMS-410, April 20, 1973.

The liquid propellant fire (S-2) safety test exposed two FSAs and two Post Impact Sphere Assemblies (PISA) to a liquid propellant residual fire. This was simulated by placing the specimens in a shallow pond of Aerozine 50 (the liquid fuel of Titan) after being preheated to the MHW-RTG operating temperature of 1090°C. The propellant was ignited and burned for a period of 20 minutes at temperatures ranging from 820° to 930°C. Post test examination revealed that the specimens showed only minor degradation and discoloring with no breaching or apparent damage (ref. 8).

The solid propellant fire (S-3) tests were designed to expose both FSAs and PISAs to the severe thermochemical environment resulting from solid propellant (UTP-3001 for Titan) combustion. Specimens were placed directly on top of (contact test) and between two (double proximity) pieces of solid propellant. Both tests utilized cubes 91 cm on a side to simulate the maximum expected fragment resulting from breakup of a Solid Rocket Motor (SRM). Of the specimens exposed to the contact fire one PICS evidenced minor, localized melting on the surface. Three of the four specimens exposed to the double proximity fire evidenced containment failure. The breaches were approximately 1.6 cm^2 and were due, not to simple melting, but to various complex high temperature reactions of the PICS and Graphite Impact Shell (GIS - the outer carbon material of the FSA) with materials such as iron and sand which were in the test environment (ref. 9).

Launch pad abort sequential (S-6) safety tests were also conducted to determine the response of MHW components to a series of likely accident environments. The tests were conducted in three phases: Phase I involved a full HSA impact at a velocity typical of a launch pad or early ascent accident; Phase II consisted of additional solid propellant fire exposure tests; and Phase III included a variety of FSA impact tests. A preheated HSA was impacted on a concrete target at a velocity of 30 meters/sec for the Phase I test, simulating free-fall of an HSA from heights consistent with launch sequences. The HSA was not fully heated prior to the test which would result in the irridium PICS being more

8. General Electric Co., Space Division, Philadelphia, PA., Safety Test No. S-2, Propellant Fire Thermochemical Effects, GEMS-413, July 1973.

9. General Electric Co., Space Division, Philadelphia, PA., Safety Test No. S-3, Solid Propellant Fire, GEMS-414, July 1973.

brittle than expected. As a result of the test, the HSA broke upon impact. None of the GISs were seriously damaged; however, several of the PICS within GHSs were cracked. Phase II of the S-6 test exposed two FSAs (one of which contained a cracked PICS from the Phase I test) and a partial HSA to a single proximity solid propellant fire in which the specimens were placed next to a 91 cm cube of solid propellant. No significant damage to the PICS was observed; however, there was some reaction of the carbon GIS, and molten steel formed from melting of a steel plate purposely introduced as part of the test environment (ref. 10).

The Phase III tests consisted of five FSA impact tests; three at velocities comparable to launch pad type velocities (30 m/s) and two at reentry velocities (85 m/s). These impacts included targets of angle iron, concrete and soil. Although the preheated PICS were severely deformed following impact against angle iron and high velocity impacts on concrete, no breaching occurred. A later FSA impact at terminal reentry velocity did result in PICS breaching (ref 11).

2. REENTRY ENVIRONMENT TESTS

In addition to the impact tests conducted as part of the S-6 Phase III testing, FSAs were impacted at terminal velocities on smooth granite, representing a severe impact condition on a hard surface. In these tests, a substantial number of the specimens tested evidenced containment failure.

The MHW aeroshell (a carbon container for the FSAs) was also subjected to reentry induced aerodynamic heating and ablation in a series of tests. These tests measured the mass loss and heat transfer and indicated that the aeroshell would not fail due to reentry. A question remains, however, that the aeroshell might fail due to thermal stress rather than ablation under certain severe, steep angle reentry conditions.

3. TESTING CONCLUSION AND LIMITATIONS

The testing program conducted to date indicates that breaching of the PICS

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10. Snow, E. C., Safety Test No. S-6, Launch Pad Abort Sequential Test Phase I: Low Velocity HSA Impact, LASL Report LA-5705-MS, Los Alamos Scientific Laboratory, New Mexico, August 1974.
11. Snow, E. C., and Frantz, C. E., Safety Test No. S-6, Launch Pad Abort Sequential Test Phase III: FSA Impacts, LASL Report LA-5855-MS, Los Alamos Scientific Laboratory, New Mexico, January 1975.

is not likely for the blast environment, liquid propellant fires, contact or single proximity fires, free FSA or HSA impact at low velocities on soil, or reentry heating. Breaching can occur in environments simulated by the double proximity solid propellant fires or upon terminal reentry velocity impacts upon concrete or granite.

A recognized limitation of many of the safety tests performed to date, largely due to the high costs of such tests, is that each test often represents only a single datum point with the results presented only on a pass/fail basis. Test conditions are often based only on the nominal, most probable, or expected environment rather than the possible ranges of environments. Extrapolation of the data available from the tests to the wide range of possible environments is difficult if not impossible; and uncertainties remain as to RTG response to environments in which it has not been specifically tested, but to which it may be exposed, even if the probabilities of such exposure are small.

The AFWL has attempted to bridge this gap between available data and the range of possible environments by developing analytical tools which can be utilized at a low cost for specific analyses. These analytical tools must, however, be based on and be consistent with current data. Increased credibility will be gained by using simple tests to verify computer models prior to applying the models to more complex systems.

4. SOLID PROPELLANT FIRE ENVIRONMENT

One program which the AFWL is pursuing vigorously is an attempt to more accurately define the Solid Propellant Fire Environment (SPFE). Although a substantial amount of information has been generated on this environment during the course of rocket motor development, it is not directly applicable to safety analyses because it is based on combustion of the propellant at the high pressure (1000 psi) inside the rocket motor, rather than at atmospheric pressure, which would be the case in the event of a catastrophic accident. The nature of the complex, two phase reacting flow of the combustion region illustrated in figure 3, inherently restricts our ability to make deterministic measurements. This severe thermochemical environment is known to be capable of causing containment failure. Specific failure mechanisms have, however, not been clearly identified. To this end, the AFWL and the Georgia Institute of Technology are attempting to measure temperatures in the flame, to identify chemical reactions of importance in the combustion region, to determine the effects of air admixture, and to

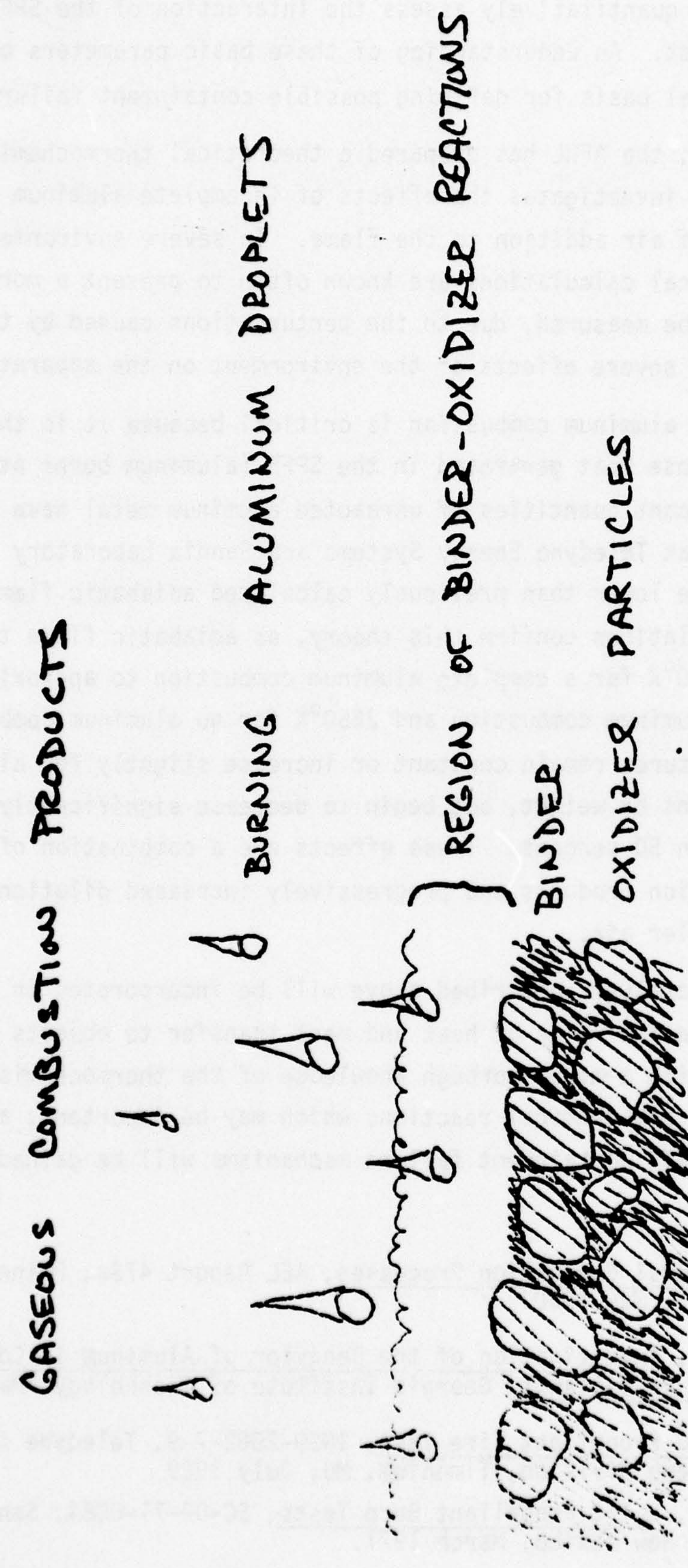

Figure 3. Combustion Zone Schematic

qualitatively and quantitatively assess the interaction of the SPFE with test objects of interest. An understanding of these basic parameters of the SPFE will provide a technical basis for defining possible containment failure mechanisms.

In particular, the AFWL has prepared a theoretical thermochemical analysis of the SPFE which investigates the effects of incomplete aluminum combustion and the effects of air addition to the flame. In severe environments such as the SPFE, analytical calculations are known often to present a more accurate picture than can be measured, due to the perturbations caused by the measuring apparatus and the severe effects of the environment on the apparatus.

The amount of aluminum combustion is critical because it is the fuel and produces the intense heat generated in the SPFE (aluminum burns at 3800°K) (refs. 12, 13). Significant quantities of unreacted aluminum metal have been noted after SPFE tests at Teledyne Energy Systems and Sandia Laboratory (refs. 14, 15), which may indicate lower than previously calculated adiabatic flame temperatures. Equilibrium calculations confirm this theory, as adiabatic flame temperatures decrease from 2900°K for a complete aluminum combustion to approximately 2750°K for 40 percent aluminum combustion and 2550°K for no aluminum combustion. Adiabatic temperatures remain constant or increase slightly for air admixtures of up to 30 percent by weight, but begin to decrease significantly for air additions greater than 50 percent. These effects are a combination of further oxidation of combustion products and progressively increased dilution of the hot products with cooler air.

The types of analyses described above will be incorporated in a model which will attempt to define rates of heat and mass transfer to objects exposed to the SPFE. Combined with a more thorough knowledge of the thermochemistry of the combustion region and chemical reactions which may be important, an increased understanding of RTG containment failure mechanisms will be gained.

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12. Glass, I., Metal Combustion Processes, AEL Report 473a, Princeton University, Trenton, N.J., May 1960.

13. Price, E. W., Investigation of the Behavior of Aluminum in Combustion of Solid Rocket Propellants, Georgia Institute of Technology, March 1975.

14. SNAP 29 Solid Propellant Fire Test, INSD-2062-7-9, Teledyne Isotopes, Nuclear Systems Division, Timonium, MD, July 1969

15. Baker, F. L., Solid Propellant Burn Tests, SC-DR-71-0084, Sandia Laboratories, Albuquerque, New Mexico, March 1971.

5. SOLID ROCKET MOTOR (SRM) IMPACT ANALYSIS

A difficult and critical problem is characterizing the response of a Solid Rocket Motor (SRM) to impact at less than terminal velocity. The fracture and subsequent propellant dispersion controls the duration and configuration of a fuel sphere assembly's (FSA) exposure to a harsh thermochemical environment created by the solid propellant fire.

The AFWL has undertaken an analytical and experimental program to characterize the SRM impact conditions necessary for fracture of the D6Ac steel casing resulting in release of potentially very large $\left(3\ \mathrm{ft}^3\right)$ pieces of burning solid propellant. This program is composed of three groups of impact tests: bare propellant impact tests, scaled SRM impact tests, and a full-scale SRM segment test.

The bare propellant impact tests recently completed tested the ignition sensitivity of the Titan III UTP-3001 solid propellant and the ability to analytically predict the impact pressures and propellant deformations (ref. 16). A series of three tests was conducted utilizing 1 to 2 foot cubes of solid propellant and impact velocities of 79 to 118 fps. The dimensions, masses, and impact velocities were shown in table 1. Perhaps the most significant result of the bare propellant tests was the ability of the finite element computer code HONDO (ref. 17) to predict stresses and deformations in the solid propellant. This code has been prepared for use in the SRM impact response analysis based upon the results of the bare propellant impact tests.

Table 1

DIMENSIONS, MASSES, AND IMPACT VELOCITIES OF BARE UTP-3001 SOLID PROPELLANT

Propellant Dimensions (cm)	Mass (kg)	Impact Velocity (m/sec)
30.5 x 30.5 x 30.5	50.2	24.1
30.5 x 30.5 x 30.5	66.8	24.4
61.0 x 61.0 x 61.0	401.8	36.0

16. Crawford, M. L., Titan III Solid Rocket Motor Impact Structural Response, Phase I: Bare Propellant Impact Tests, AFWL TR-77-87, 1977

17. Key, S. W., HONDO-A Finite Element Computer Program for the Large Deformation Dynamic Response of Axisymmetric Solids, SLA-74-0039, Sandia Laboratories, Albuquerque, NM, April 1974

The next phase will be the impact of a series of scaled SRM models. The dimensions of the models will be based on a 1/6 linear scale, and will include the use of an inert solid propellant simulant. Five single segments will be impacted at various velocities, orientations, and impacting media, followed by a full five segment scaled SRM impacted at the conditions deemed to be the most probable for an actual launch abort. The results of these tests are intended to show the structural integrity of the scaled motor casings after impact. The HONDO will be used to simulate the impacts, and its ability to predict fracture of the motor casings will be evaluated.

The final phase of the program will be the impact of an actual Titan III-C SRM segment. The impact conditions will be determined based on the results of the initial phases of the program. The results of this full-scale test will provide overpressure as well as fragmentation and dispersion data.

The proposed combined analytical and experimental program will provide critical SRM fragmentation data which is presently unavailable.

SECTION IV

AFWL REVIEW FOR THE LINCOLN EXPERIMENTAL SATELLITES 8 AND 9 (LES 8/9)

The typical use of the preceding analytical techniques and environment definitions were demonstrated in independent Air Force assessment of LES 8/9. The event/consequence trees (modified fault trees) were used with FMEA data to determine the occurrence probabilities of each potential accident. The FMEA data were modified based on a historical missile reliability study (ref. 18) to develop credible accident probabilities consistent with available NASA and DOD launch experience. The event trees traced the expected sequence of events leading to accidents (with or without fuel release) and subsequent system response. The system response analysis was based on a nominal model of RTG integrity resulting from the safety tests and available analytical capability discussed in the preceding section.

For the AFWL analysis, the launch sequence was divided into 10 parts based on the times into launch yielding significant variations in missile systems response or potential accident environments. A typical accident sequence tree, "Early Ascent 1, Phase 2A" is shown in figures 4a and 4b. The 5-to 12-second time phase, with destruct action malfunction and full vehicle impact, is representative of the logic development used in the entire LES 8/9 analyses. This portion of the launch sequence is significant because there is no down range velocity component with potential launch pad impact. Following the paths shown, specifically structural failures and incorrect staging, the FMEA data and component analysis provided the conditional probabilities shown ($P_{structural}$ = 0.5898 and $P_{staging}$ = 0.0053). Next in the sequence is the Range Safety Officer's (RSO) opportunity and ability to utilize CSDS (command destruct). This probability is an estimate based on the time required for RSO response with system response requirements. Assuming the next action is destruct failure (based on Eastern Test Range data, P = 0.05), structural analysis indicated the full vehicle or major portion of the vehicle (Titan IIIC) would impact. The consequences of the impact are based on an analysis of numerous subsystem (fuel

18. Thornton, M.A., LAUNCH, A Computer Code for Determining Launch Vehicle Reliability, AFWL-TR-77-126, Kirtland AFB, New Mexico, 1977.

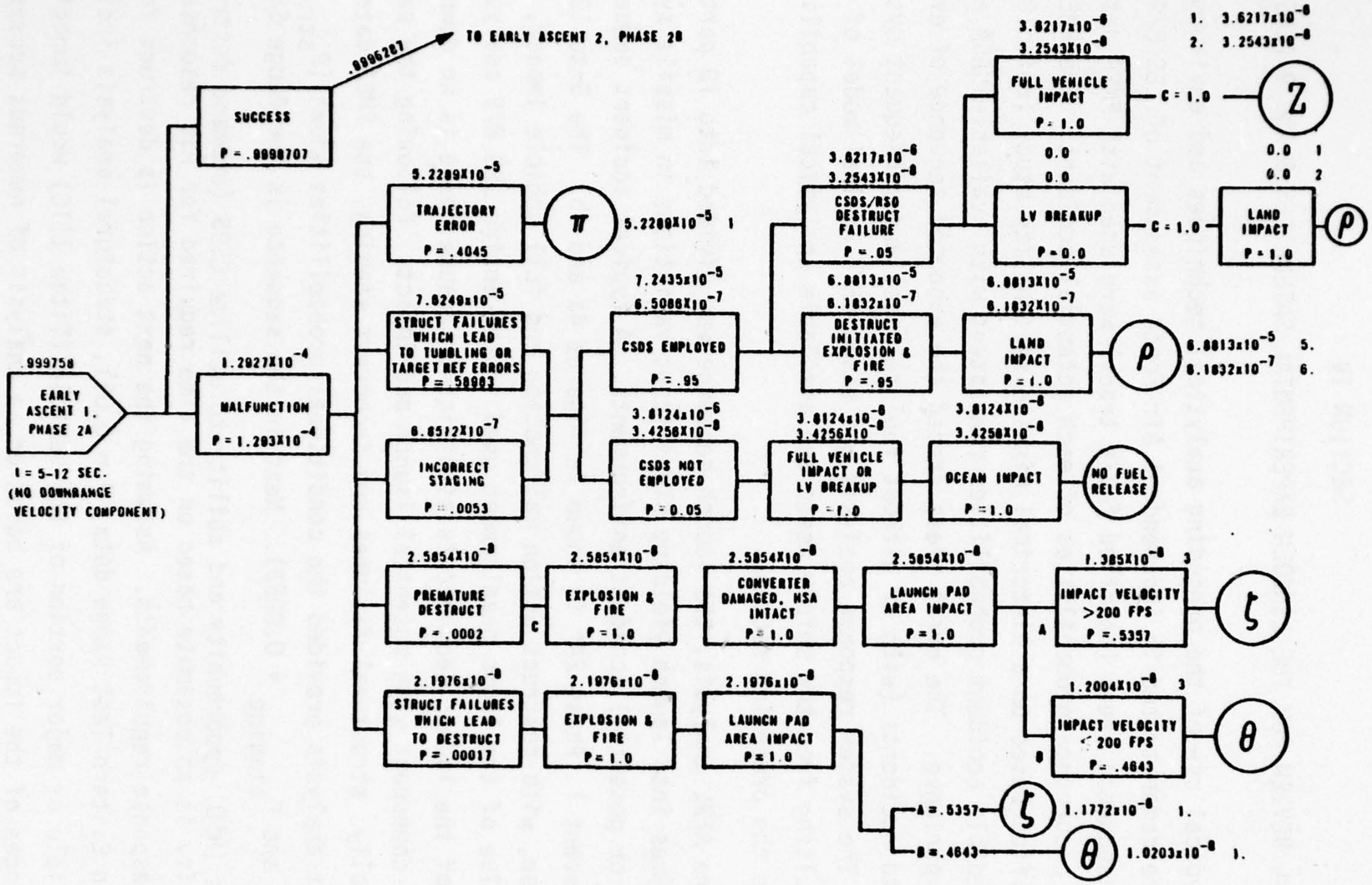

Figure 4a. Early Ascent 1, Phase 2A

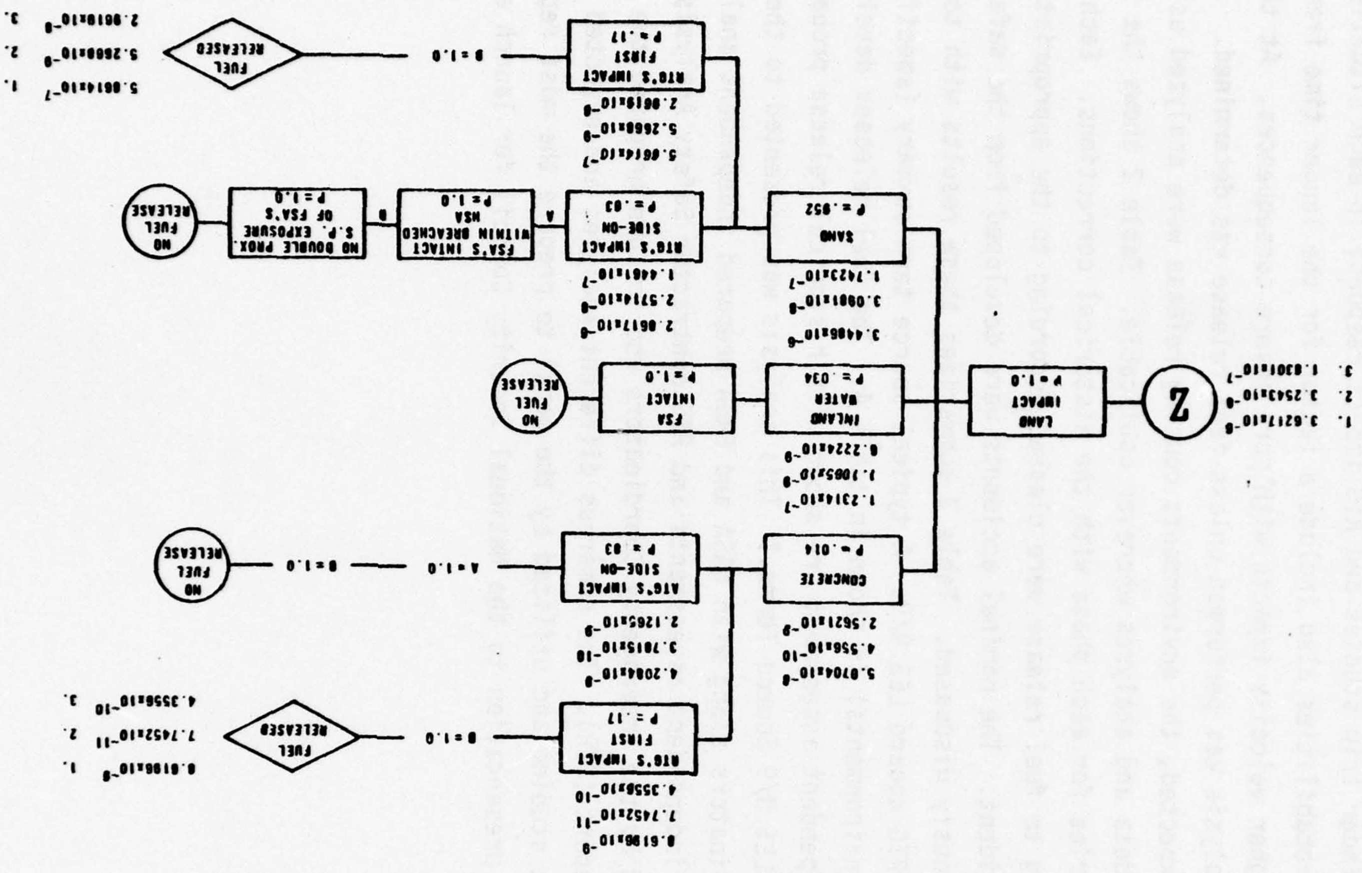

Figure 4b. Early Ascent 1, Phase 2A, Branch Z

assemblies) impact tests performed and analyzed by Los Alamos Scientific Laboratory (LASL). The land description was based on Kennedy Space Center (KSC) land use studies. The orientation of the RTG was largely engineering judgment utilizing cylinder trip studies and RTG impact response in each situation. The conditional probabilities also include a factor for the longer time frame resulting in higher velocity impacts with more severe consequences. At this point, no further analysis was performed unless fuel release was determined. If fuel release was expected, the environments causing release were analyzed using LASL experimental data and analyses wherever applicable. Table 2 shows the probability summaries for each phase with the historical corrections. Each of the events leading to fuel release were classed according to the appropriate "nominal" accident. The nominal accidents were developed from the safety test results previously discussed. Table 3 summarizes these results with totals for the four MHW RTG aboard LES 8/9. A typical source term summary (specifically for LES 8/9 environments) is shown in table 4. The fuel releases developed in the AFWL independent assessment are shown with historical release probabilities in table 5, "LES 8/9 Source Terms." This analysis was presented to the INSRP and its coordinators along with NASA and ERDA prepared independent analyses. The combined independent assessments and RTG contractor Safety Analysis Report were reviewed by the Interagency Coordinators who in turn prepared the Safety Evaluation Report (SER). The numerous different analyses and expected consequences are studied and utilized by the panel to prepare the most representative SER for presentation to the National Security Council for launch approval.

Table 2

LES 8/9 FUEL RELEASE PROBABILITY SUMMARY

Phase	Fuel Release Probability Based on Historical Data	Historical/FMEA Correction Factor	Mode of Failure
1, Prelaunch t < 0 But After Core Fueling	0.0	---	N/A
2, Launch t = 0 - 5 sec	3.6×10^{-10}	11.0115	Double Proximity Solid Propellant Fire
2A, Early Ascent 1 t = S - 12 sec	1.2×10^{-5}	11.0115	Powered Impact on Sand
	1.8×10^{-7}		Powered Impact on Rock
	1.8×10^{-8}		Solid Fire (DP) V > 200 fps
	3.6×10^{-8}		LP - SF - DP V > 200 fps
	5.5×10^{-7}		LP - SF - SP V > 200 fps
	4.4×10^{-4}		LP Impact V > 200 fps
	2.3×10^{-11}		SF - DP V > 200 fps
	4.5×10^{-11}		SF - SP V > 200 fps
	1.1×10^{-6}		Impact V > 200 fps
2B, Early Ascent 2 t = 12 - 422 sec	2.2×10^{-6}		Powered Impact on Sand
	4.1×10^{-8}	20.824	Powered Impact on Rock
	3.2×10^{-5}		Impact V > 200 fps
3, Ascent t = 22 - 482 sec	3.3×10^{-7}		Powered Impact on Sand
	8.0×10^{-9}	2.5569	Powered Impact on Rock
	4.0×10^{-7}		Impact V > 200 fps

Table 2 (Cont'd)

Phase	Fuel Release Probability Based on Historical Data	Historical/FMEA Correction Factor	Mode of Failure
4, Parking Orbit t = 482 - 4122 sec	1.4×10^{-4}	2.5569	Impact Rock V > 200 fps
5, Transfer Orbit t = 4122 - 4439 sec	1.7×10^{-5}	2.2874	Impact Rock V > 200 fps
6, Transfer Orbit Coast t = 4439 - 23,313 sec	1000 year orbit	2.2874	
7, Orbit Acquisition t = 23,313 - 23, 424 sec	2.0×10^{-4}	2.2874	Impact Rock V > 200 fps
Escape	2.4×10^{-5}		

Table 3

SUMMARY OF ACCIDENTS LEADING TO FUEL RELEASE

Accident	Description	Exposure	Total
1	Double Proximity Fire/HSA Impact Velocity Less than 800 fps/S-6 Phase 1 Nominal	2 FSAs Intact	02
2	Powered Impact on Sand/No Solid Fire Exposure/Sandia Sled Impact-Nominal/ 10% Normal Operation St Resuspension/ Medium Crack	9 Breached PISAs/HSA	36
		24 Normal Ops/HSA	96
3	Powered Impact On Concrete/No Solid Propellant Exposure/GE FSAR-Nominal/ Large Crack/10% Normal Operation St Resuspension	19 Breached PISAs/HSA	76
		24 Normal OPS/HSA	96
4A	Double Proximity Fire/Launch Pad Impact/ HSA Impact Velocity Greater than 200 fps/ Destruct Action/25% of FSAs Roll Away Upon Impact/Sandia Sled Test-Nominal/ 5% Normal Operation St Resuspension	(SF/4HSAs)	
		10 FSAs Intact	10
		3 Breached PISA w/GIS	3
		1 Free PISA	1
		1, 1, 2 Breached PISAs	4
		18 Normal Ops Vapor	18
		(Impact/4HSAs)	
		3, 3, 10 Breached PISAs	16
		23 Normal Ops	23
4B	Single Proximity Fire/Launch Pad Impact/ HSA Impact Velocity Greater than 200 fps/ Destruct Action/75% of FSAs Roll Away Upon Impact/Sandia Sled Test-Nominal/ 5% Normal Operation St Resuspension	(SF/4HSAs)	
		2M Breached PISA	1
		1 PISA	1
		2 Normal Ops Vapor	1
		(Impact/4HSAs)	
		[a]4, [b]3, [c]12 Breached PISAs	19
		26 Normal Ops	26

Note: See footnotes at end of table

Table 3 (Cont'd)

Accident	Description	Exposure	Total
		(Impact/4HSAs)	
4C	Impact-Launch Pad Area/HSA Impact Velocity Greater than 200 fps/Destruct Action/ Sandia Sled Test-Nominal/5% Normal Operation St Resuspension	$^{a}{}_{4}$, $^{b}{}_{4}$, $^{c}{}_{12}$ Breached PISAs	20
		28 Normal Ops	28
		(SF/4HSAs)	
5A	4A Except Impact is Not Limited to the Launch Pad Area	10 FSAs	10
		3 Breached PISA w/GIS	3
		1 PISA	1
		$^{a}{}_{1}$, $^{b}{}_{1}$, $^{c}{}_{2}$ Breached PISAs	4
		18 Normal Ops Vapor	18
		(Impact/4HSAs)	
		1S Breached PISA	1
		2 Normal Ops	2
		(SF/4HSAs)	
5B	4B Except Impact is Not Limited to the Launch Pad Area	1M Breached PISA	1
		1 PISA	1
		2 Normal Ops	2
		(Impact/4HSAs)	
		1L, 3S Breached PISAs	4
		5 Normal Ops	5
5C	4C Except Impact is Not Limited to the Launch Pad Area/Applicable to Reentry Impacts	$^{a}{}_{1}$, $^{b}{}_{1}$, $^{c}{}_{3}$ Breached PISAs	5
		7 Normal Ops	7

a = Number with Large Cracks
b = Number with Medium Cracks
c = Number with Small Cracks
Releases with Crack Size Were Determined From Test Data

Table 4

AFWL MHW SOURCE TERM SUMMARY
(mCi/FSA)

Accident	Environment	Impact	Solid Fire
Normal Operation	> 200 fps	0.5	10
	Powered	1.0	N/A
Impact	Large	8.0	380
	Medium	2.0	190
	Small	0.04	4
Single Proximity	(PISA Only)		400
Double Proximity (PISA or FSA)			400

Table 5

LES 8, 9 SOURCE TERMS

Accident	Probability	Vapor (mCi)	Particulates (mCi)
1	2.2 E-8	800	
2	1.2 E-5		168
3	1.0 E-7		400
1	1.8 E-8	8000	
4A	3.6 E-8	8000	30
4B	5.5 E-7	1000	35
4C	4.4 E-4		38
1	1.6 E-11	800	
5A	2.3 E-11	8000	1
5B	4.5 E-11	1000	7
5C	1.1 E-6		10
2	2.2 E-6		168
3	4.1 E-8		4000
5C	3.2 E-5		10
2	3.3 E-7		168
3	4.9 E-9		400
5C	1.5 E-7		10
5C	2.4 E-7		10
5C	1.4 E-4		10
5C	1.7 E-5		10
5C	1.9 E-4		10

SECTION V

ENVIRONMENTAL STATEMENT

The National Environmental Policy Act of 1969 (NEPA) and other legislation declared a national policy that encourages, among other things, productive and enjoyable harmony between man and his environment, promotes efforts that will prevent or eliminate damage to the environment and biosphere, and that will stimulate the health and welfare of man. Guidelines and directives for the production of Environmental Statements (ES) are also called forth. The AFR 19-2 "establishes policies, assigns responsibilities, and provides guidance for the preparation of environmental assessments and statements." The key is the direction to assess the environmental consequences of any proposed action at the earliest stage practicable, and to use these assessments in the decision making process.

Guidelines of the Council of Environmental Quality (CEQ) and the DOD have dictated that for actions such as the Air Force launch of a space nuclear power source, the following actions are required:

a. An environmental assessment be prepared prior to Defense System Acquisition Review Council (DSARC) I.

b. A candidate environmental statement be prepared prior to DSARC II.

c. A final environmental statement be prepared at least 30 days prior to final action.

Figure 5 is a flow chart, taken from AFR 19-2, for the processing of a typical ES. It is worth noting that since the ES is prepared very early in the system development process, complete mission and design data are not available and the analysis performed does not have the depth or breadth of that performed for the INSRP. It is certainly not a substitute for the INSRP process, but can be a useful adjunct.

The AFWL prepared the ES for the LES 8/9 launch (ref. 19), and the format of this statement is outlined to show the areas covered. As would be expected,

19. Final Environmental Statement, Lincoln Experimental Satellites 8 and 9 (LES 8/9) Program, USAF, December 1975.

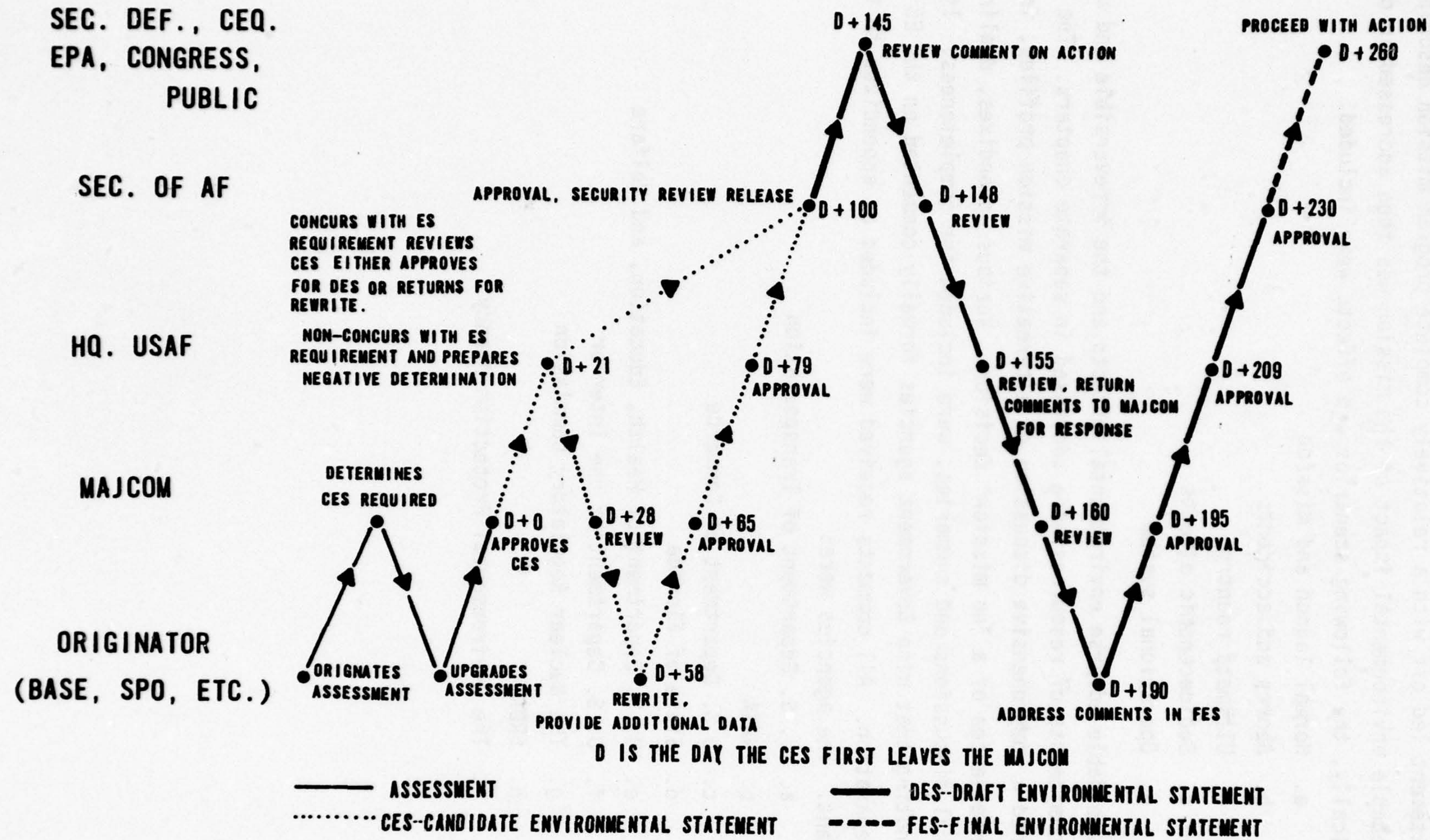

Figure 5. Flow Chart for Processing of Typical Environmental Statement (EIS)

the statement led off with a relatively complete program mission description. The probable environmental impact of the mission was then addressed in detail. Specifically, the following scenarios and effects were included.

a. Normal launch and mission
b. Aborts and accidents
c. Ultimate reentry
d. Socioeconomic effects
e. Operational system

Unavoidable adverse environmental effects and the irreversible and unretrievable commitments of resources were addressed in separate chapters. The ES also contained a comprehensive discussion of alternative mission profiles, including the consequences of a "no mission" decision. Various appendixes, dealing with technical discussions and summaries, were included for completeness. It is worth noting that nine Government agencies formally commented on the ES during its preparation. All comments received were included as appendixes to the final statement. The agencies were:

a. U. S. Department of Transportation
b. NASA
c. U.S. Department of Commerce
d. State of Florida
e. U. S. Department of Health, Education, and Welfare
f. U. S. Department of the Interior
g. The Nuclear Regulatory Commission
h. ERDA
i. The Environmental Protection Agency

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5. Methodology Study for Preorbital Aborts, Teledyne Energy Systems, AFWL-TR-76-223 (Revised), Air Force Weapons Laboratory, Kirtland AFB, NM, 1976.

6. SNAP 19/Viking '75 Final Safety Analysis Report, Teledyne Energy Systems, ESD-3069-15, Timonium, MD., August 1974.

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9. General Electric Co., Space Division, Philadelphia, PA, Safety Test No. S-3, Solid Propellant Fire, GEMS-414, July 1973.

10. Snow, E. C., Safety Test No. S-6, Launch Pad Abort Sequential Test Phase I: Low Velocity HSA Impact, LASL Report LA-5705-MS, Los Alamos Scientific Laboratory, New Mexico, August 1974.

11. Snow, E. C., and Frantz, C. E., Safety Test No. S-6, Launch Pad Abort Sequential Test Phase III: FSA Impacts, LASL Report LA-5855-MS, Los Alamos Scientific Laboratory, New Mexico, January 1975.

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15. Baker, F. L., Solid Propellant Burn Tests, SC-DR-71-0084, Sandia Laboratories, Albuquerque, New Mexico, March 1971.

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17. Key, S. W, HONDO-A Finite Element Computer Program for the Large Deformation Dynamic Response of Axisymmetric Solids, SLA-74-0039, Sandia Laboratories, Albuquerque, NM, April 1974.

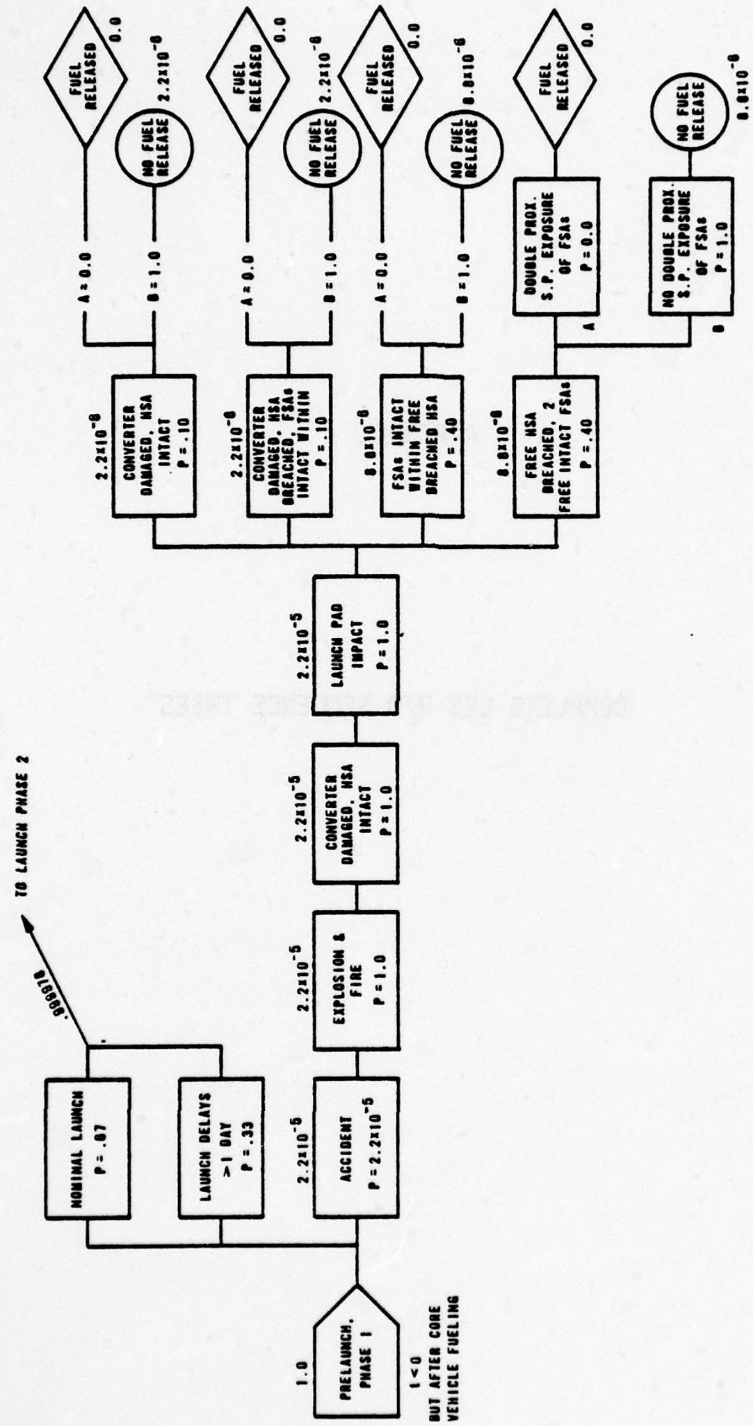
18. Thornton, M.A, LAUNCH, A Computer Code for Determining Launch Vehicle Reliability, AFWL-TR-77-126, 1977.

19. Final Environmental Statement, Lincoln Experimental Satellites 8 and 9 (LES 8/9) Program, USAF, December 1975.

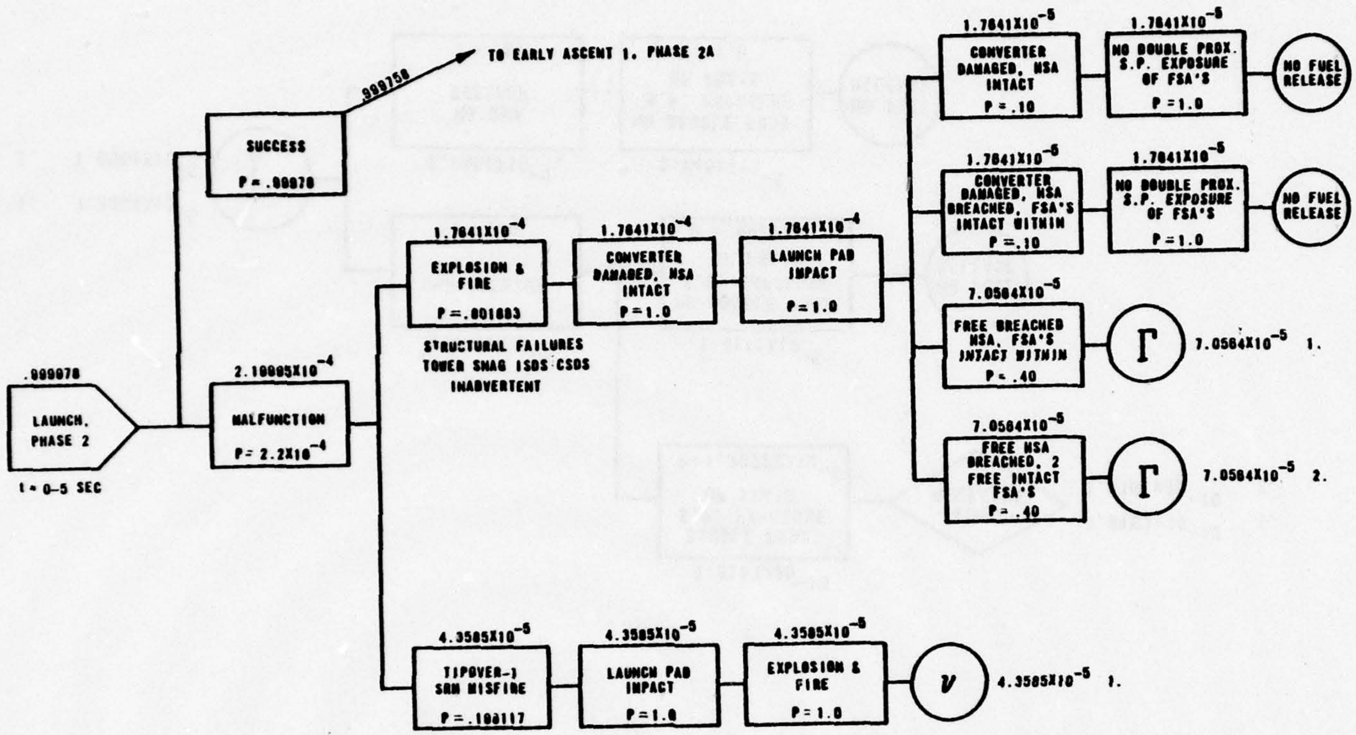
APPENDIX

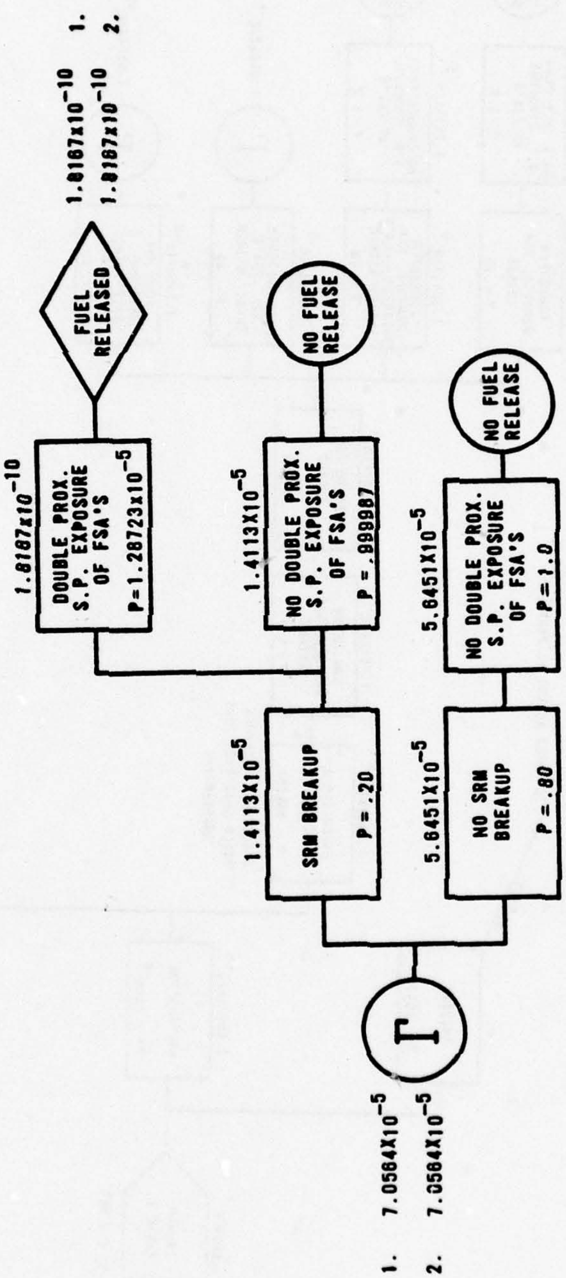
COMPLETE LES 8/9 SEQUENCE TREES

PRELAUNCH, PHASE I



LAUNCH PHASE 2

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2. 7.0564X10^-5
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P = .80
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DOUBLE PROX. S.P. EXPOSURE OF FSA'S
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1.4113X10^-5
NO DOUBLE PROX. S.P. EXPOSURE OF FSA'S
P = .999987
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NO DOUBLE PROX. S.P. EXPOSURE OF FSA'S
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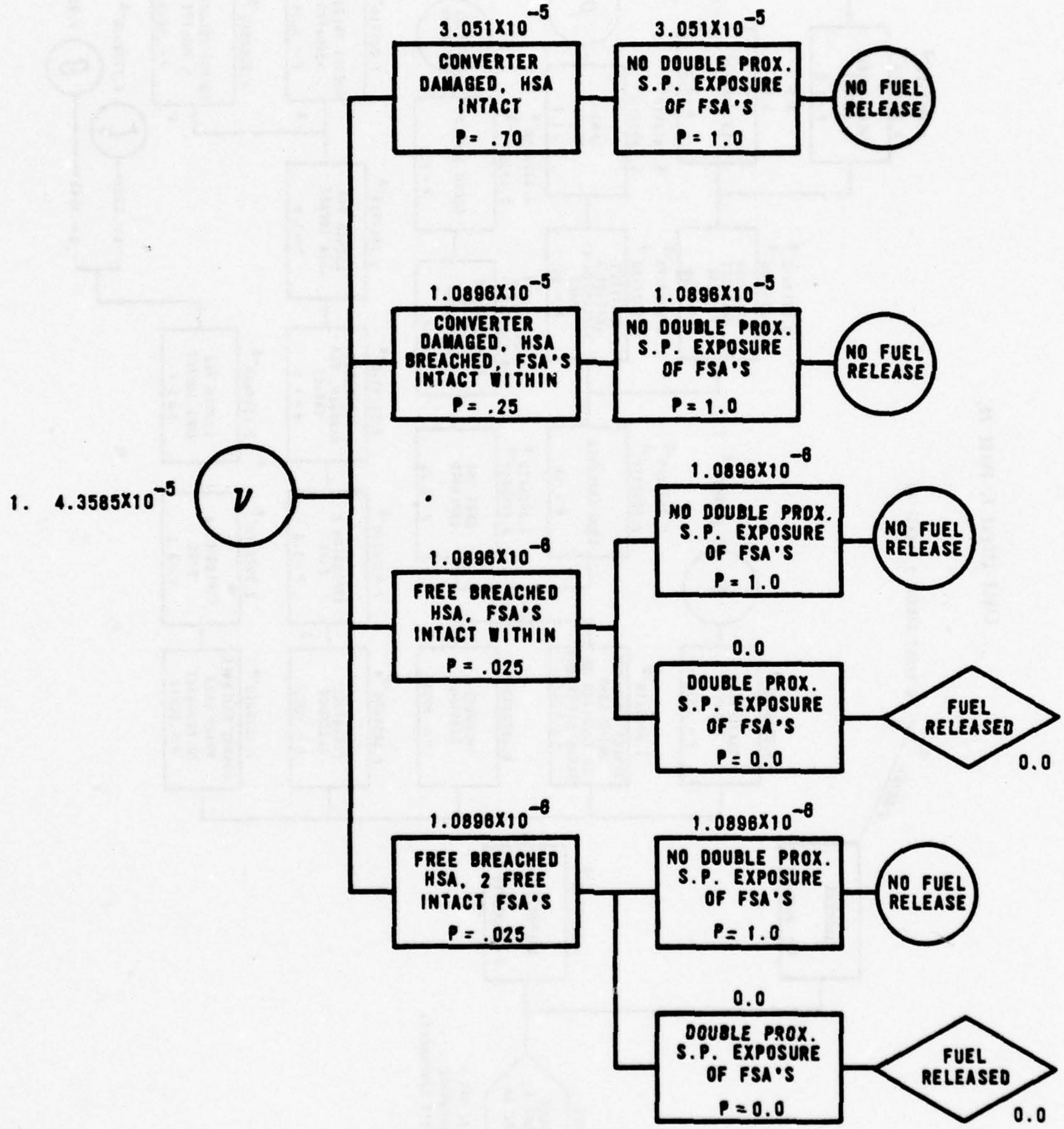
1.8187x10^-10 2.
NO FUEL RELEASE
NO FUEL RELEASE


1. 4.3585X10^-5
ν
3.051X10^-5
CONVERTER DAMAGED, HSA INTACT
P= .70
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NO DOUBLE PROX. S.P. EXPOSURE OF FSA'S
P=1.0
NO FUEL RELEASE
1.0896X10^-5
CONVERTER DAMAGED, HSA BREACHED, FSA'S INTACT WITHIN
P= .25
1.0896X10^-5
NO DOUBLE PROX. S.P. EXPOSURE OF FSA'S
P=1.0
NO FUEL RELEASE
1.0896X10^-6
FREE BREACHED HSA, FSA'S INTACT WITHIN
P= .025
1.0896X10^-6
NO DOUBLE PROX. S.P. EXPOSURE OF FSA'S
P=1.0
NO FUEL RELEASE
0.0
DOUBLE PROX. S.P. EXPOSURE OF FSA'S
P=0.0
FUEL RELEASED
0.0
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FREE BREACHED HSA, 2 FREE INTACT FSA'S
P= .025
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FUEL RELEASED
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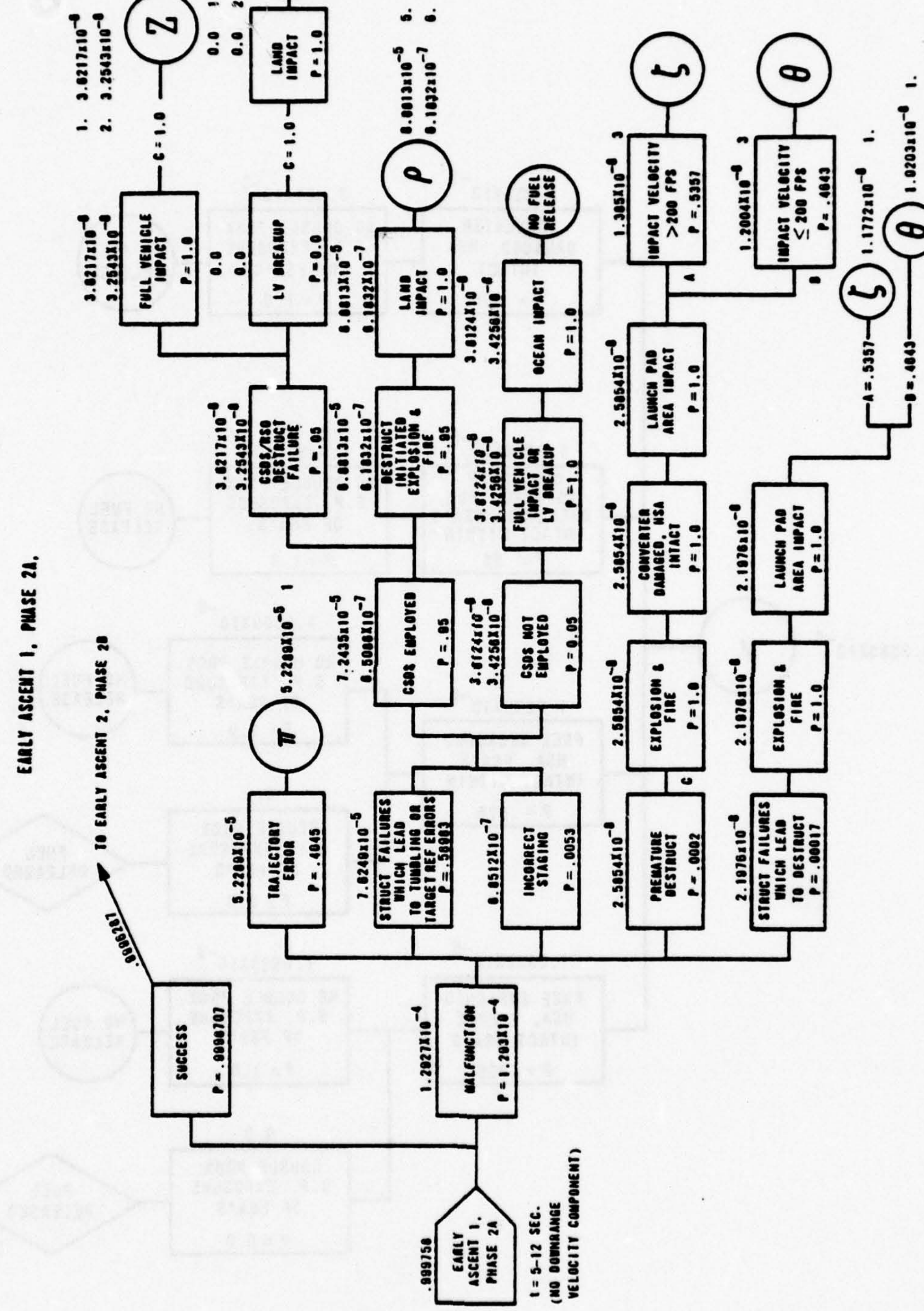
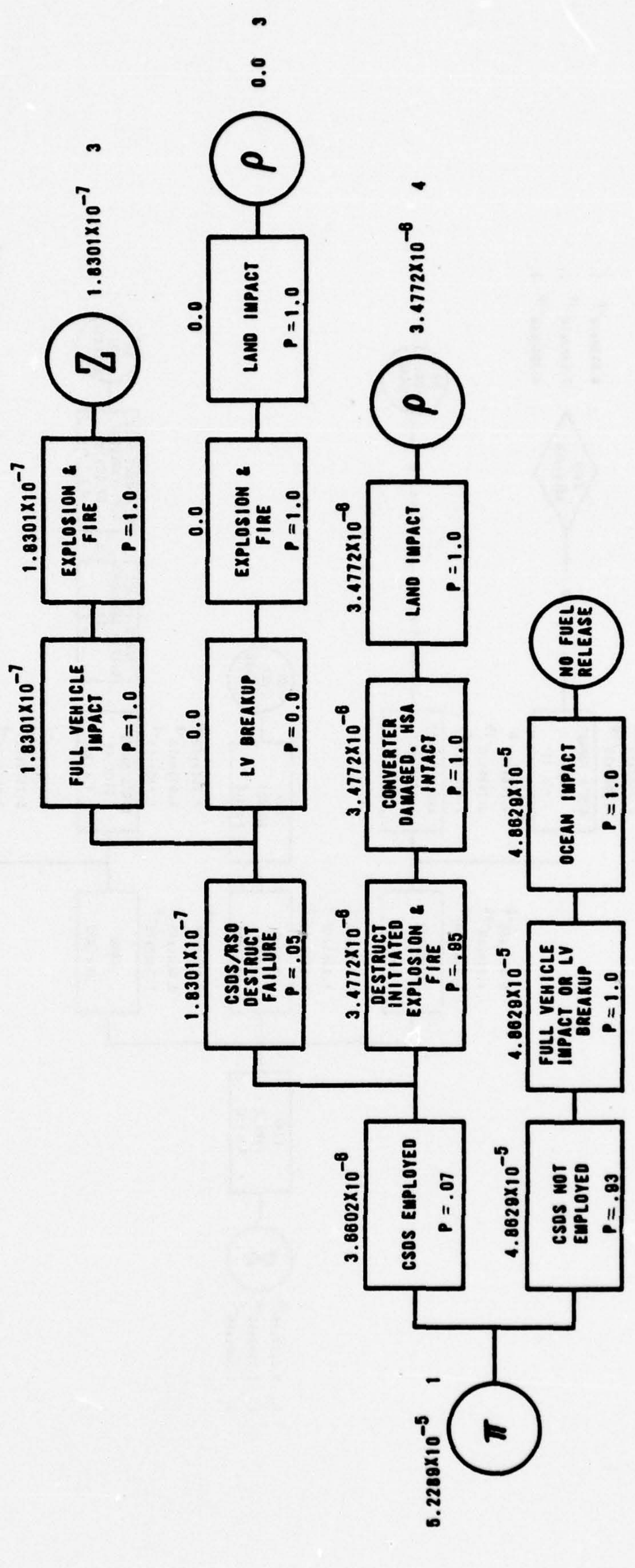


EARLY ASCENT 1, PHASE 2A.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CSDS NOT EMPLOYED
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CSDS/RSO DESTRUCT FAILURE
P = .05
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DESTRUCT INITIATED EXPLOSION & FIRE
P = .95
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FULL VEHICLE IMPACT OR LV BREAKUP
P = 1.0
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FULL VEHICLE IMPACT
P = 1.0
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LV BREAKUP
P = 0.0
0.0
CONVERTER DAMAGED, HSA INTACT
P = 1.0
3.4772X10^-6
OCEAN IMPACT
P = 1.0
4.8629X10^-5
NO FUEL RELEASE
EXPLOSION & FIRE
P = 1.0
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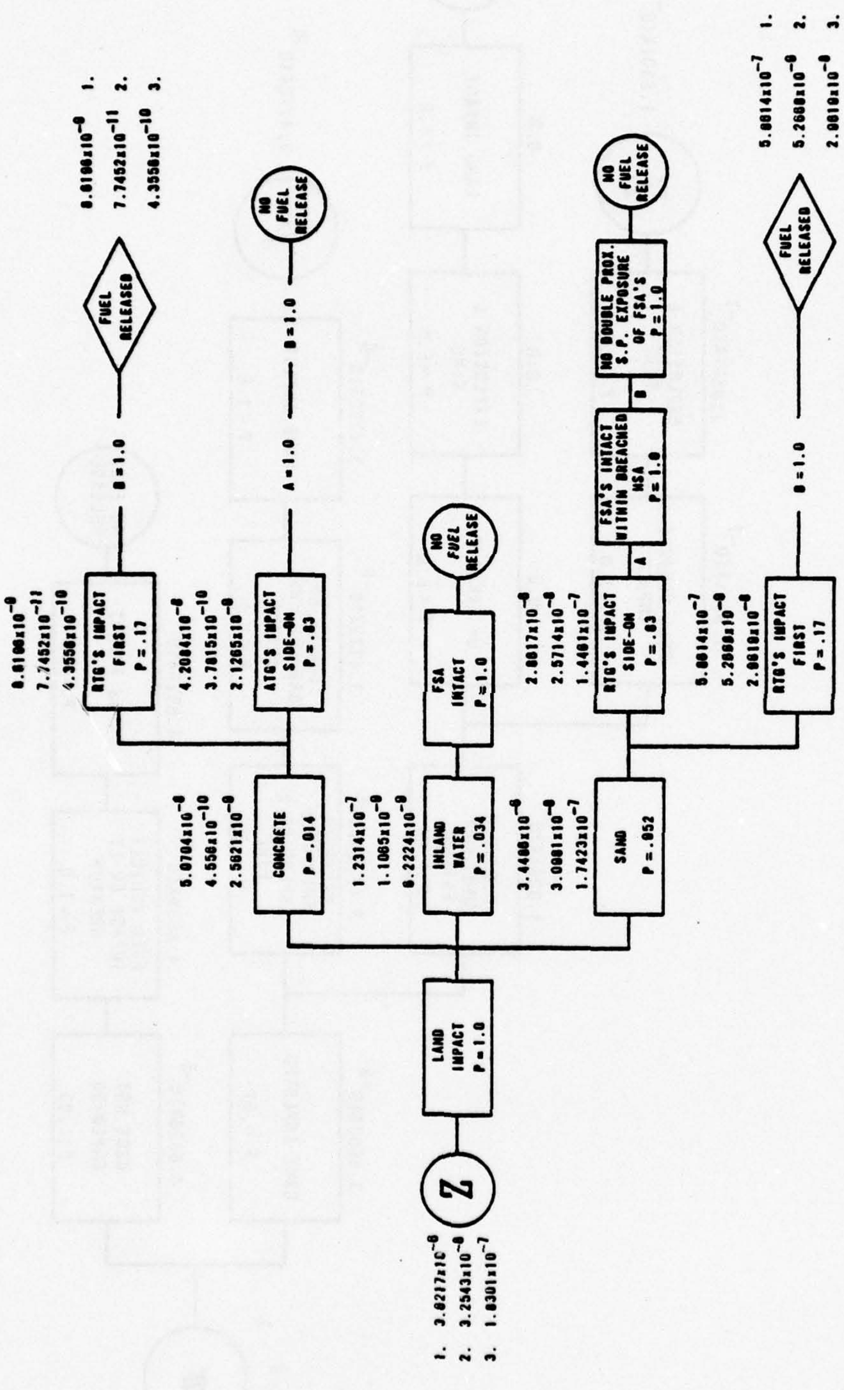
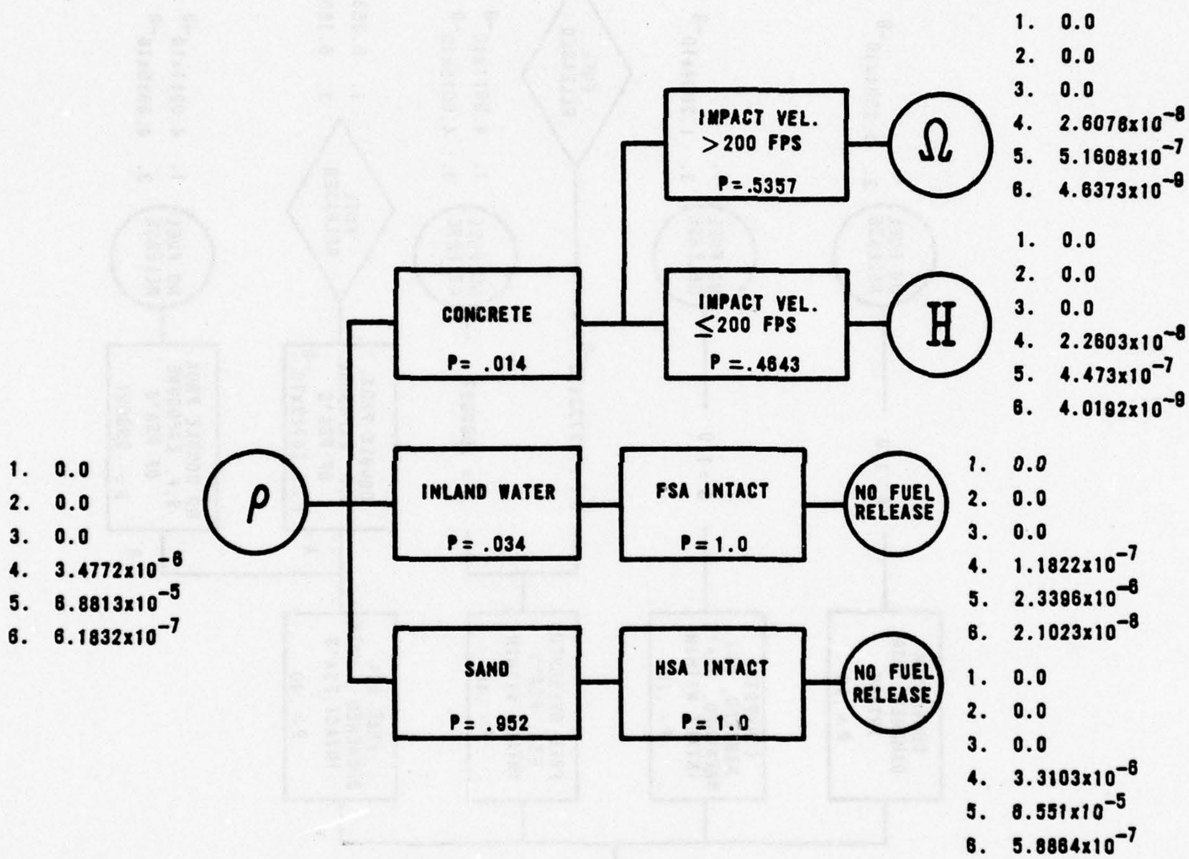
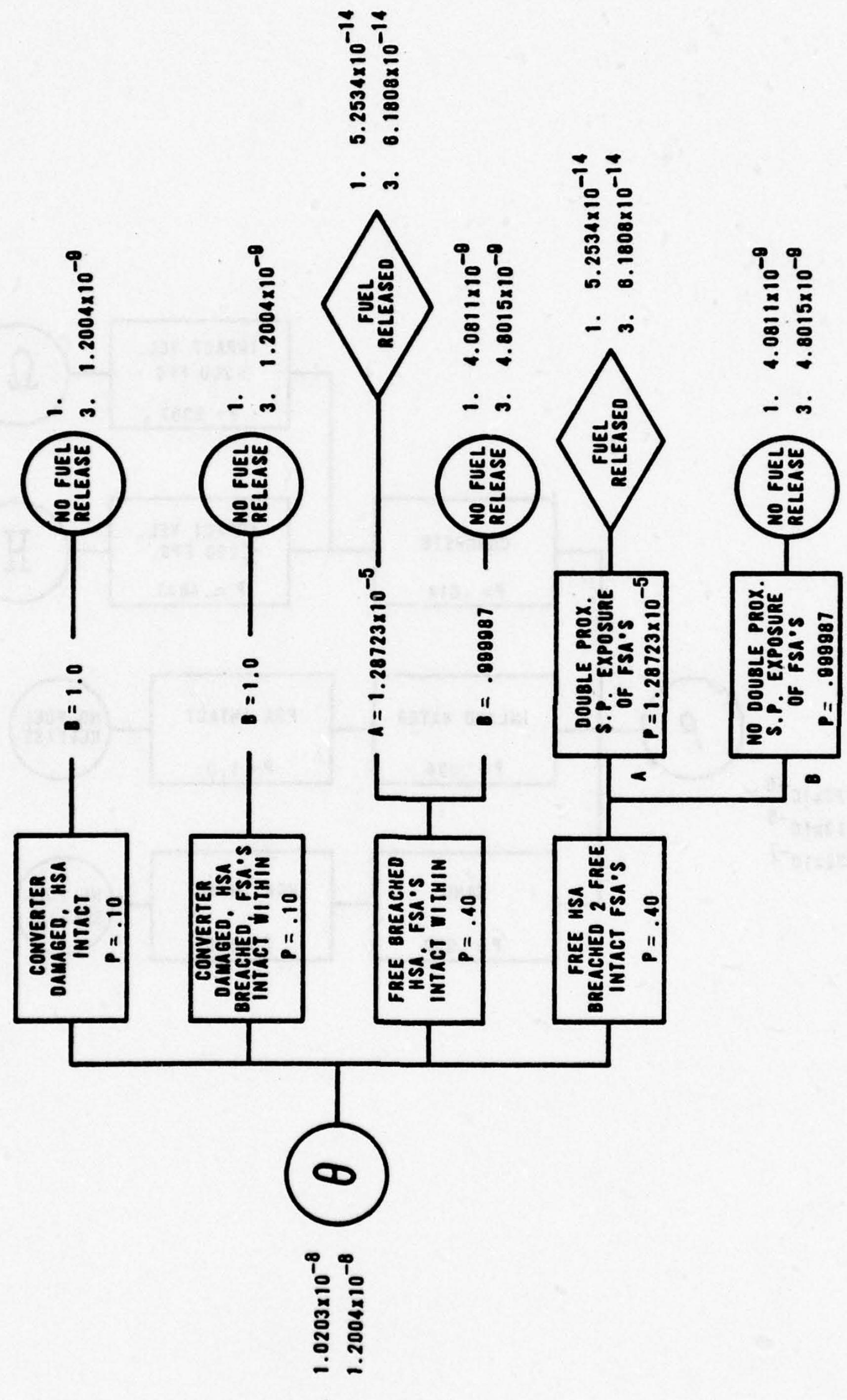
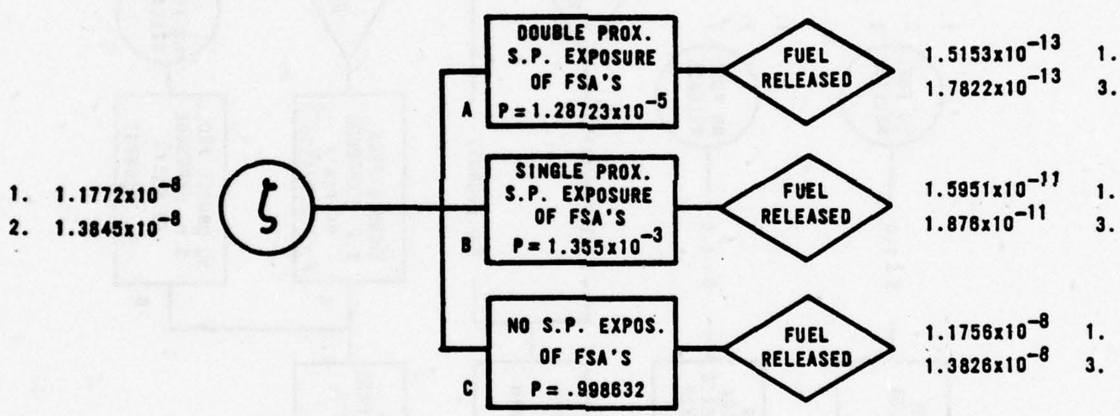
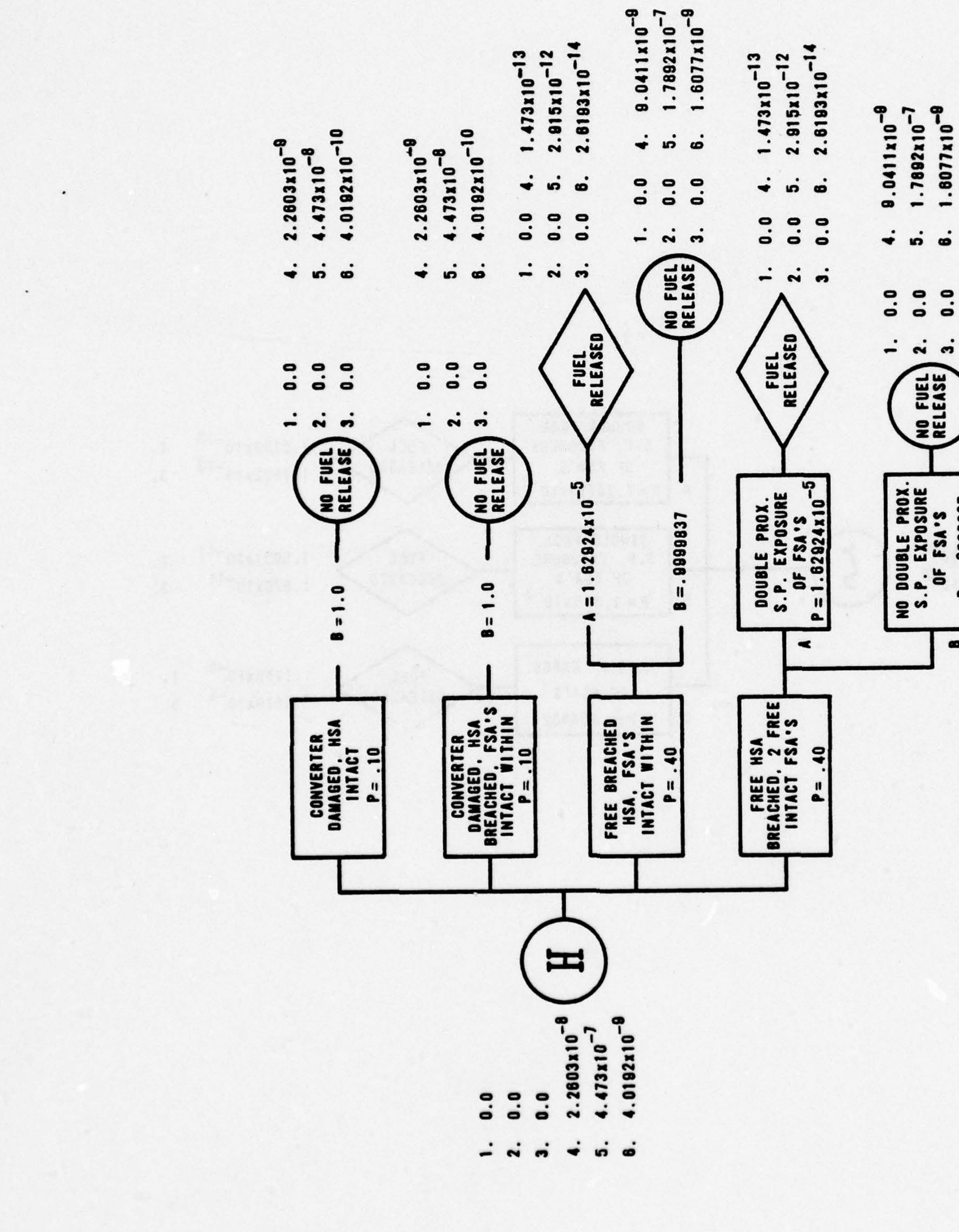
EXPLOSION & FIRE
P = 1.0
0.0
LAND IMPACT
P = 1.0
3.4772X10^-6
Z
1.8301X10^-7 3
LAND IMPACT
P = 1.0
0.0
ρ
0.0 3
ρ
3.4772X10^-6 4

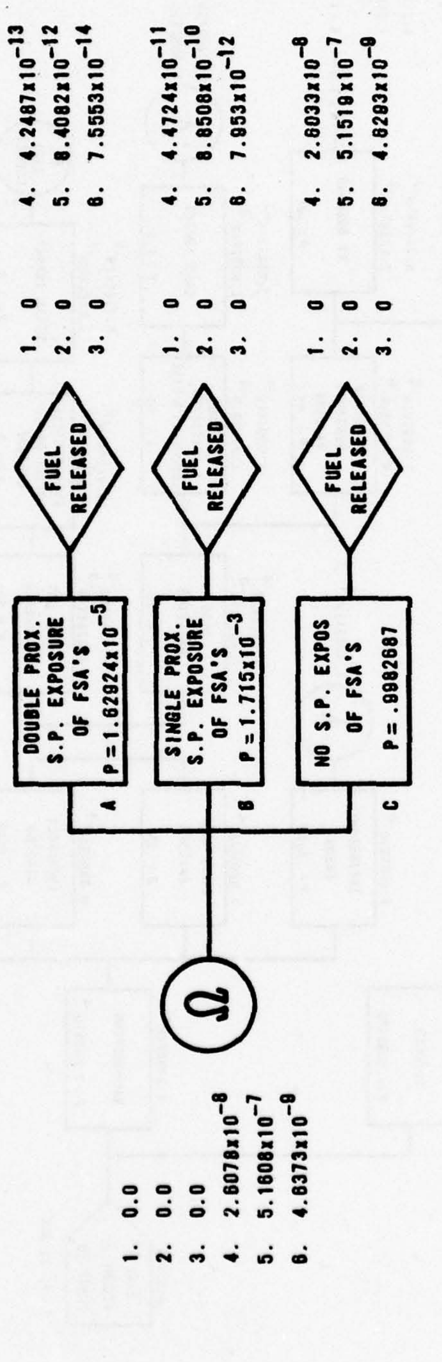

1. 3.8217x10^-8
2. 3.2543x10^-8
3. 1.8301x10^-7
Z
LAND IMPACT P=1.0
CONCRETE P=.014
5.0704x10^-8
4.556x10^-10
2.5621x10^-9
INLAND WATER P=.034
1.2314x10^-7
1.1065x10^-9
8.2224x10^-9
SAND P=.052
3.4400x10^-8
3.0081x10^-8
1.7423x10^-7
RTG'S IMPACT FIRST P=.17
8.8100x10^-9
7.7452x10^-11
4.3550x10^-10
B=1.0
FUEL RELEASED
8.8100x10^-9 1.
7.7452x10^-11 2.
4.3550x10^-10 3.
ATG'S IMPACT SIDE-ON P=.83
4.2084x10^-8
3.7815x10^-10
2.1265x10^-9
A=1.0
B=1.0
NO FUEL RELEASE
FSA INTACT P=1.0
NO FUEL RELEASE
RTG'S IMPACT SIDE-ON P=.83
2.8817x10^-8
2.5714x10^-8
1.4481x10^-7
A
FSA'S INTACT WITHIN BREACHED HSA P=1.0
B
NO DOUBLE PROX. S.P. EXPOSURE OF FSA'S P=1.0
NO FUEL RELEASE
RTG'S IMPACT FIRST P=.17
5.8814x10^-7
5.2680x10^-9
2.9810x10^-8
B=1.0
FUEL RELEASED
5.8814x10^-7 1.
5.2680x10^-9 2.
2.9810x10^-8 3.


1. 0.0
2. 0.0
3. 0.0
4. 2.6078x10^-8
5. 5.1608x10^-7
6. 4.6373x10^-9
IMPACT VEL.
>200 FPS
P=.5357
Ω
1. 0.0
2. 0.0
3. 0.0
4. 2.2603x10^-8
5. 4.473x10^-7
6. 4.0192x10^-9
CONCRETE
P= .014
IMPACT VEL.
≤200 FPS
P =.4643
H
1. 0.0
2. 0.0
3. 0.0
4. 3.4772x10^-6
5. 6.8813x10^-5
6. 6.1832x10^-7
ρ
INLAND WATER
P= .034
FSA INTACT
P=1.0
NO FUEL RELEASE
1. 0.0
2. 0.0
3. 0.0
4. 1.1822x10^-7
5. 2.3396x10^-6
6. 2.1023x10^-8
SAND
P= .952
HSA INTACT
P= 1.0
NO FUEL RELEASE
1. 0.0
2. 0.0
3. 0.0
4. 3.3103x10^-6
5. 6.551x10^-5
6. 5.8864x10^-7

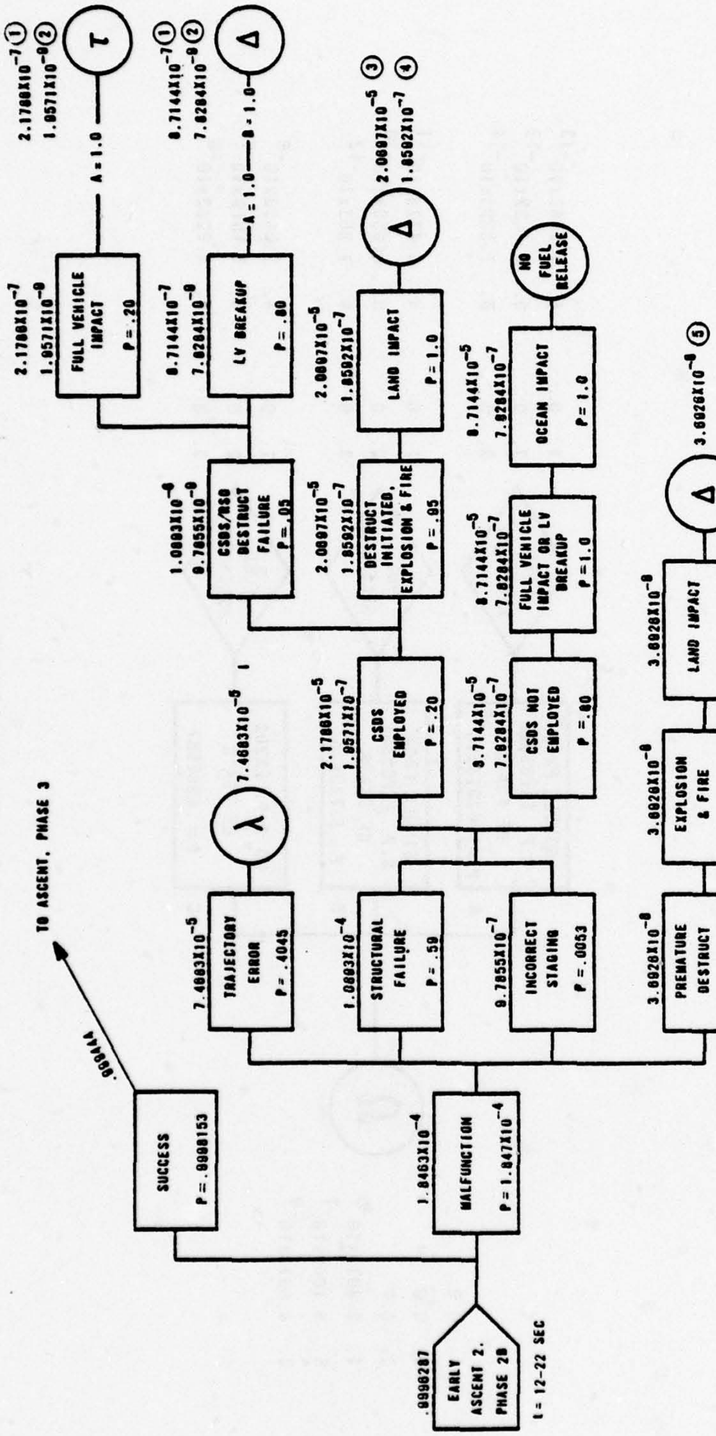

θ
1. 1.0203×10^{-8}
2. 1.2004×10^{-8}
CONVERTER DAMAGED, HSA INTACT
P = .10
B = 1.0
NO FUEL RELEASE
1.
3. 1.2004×10^{-8}
CONVERTER DAMAGED, HSA BREACHED, FSA'S INTACT WITHIN
P = .10
B = 1.0
NO FUEL RELEASE
1.
3. 1.2004×10^{-8}
FREE BREACHED HSA, FSA'S INTACT WITHIN
P = .40
A = 1.28723×10^{-5}
FUEL RELEASED
1. 5.2534×10^{-14}
3. 6.1808×10^{-14}
B = .999987
NO FUEL RELEASE
1. 4.0811×10^{-9}
3. 4.8015×10^{-9}
FREE HSA BREACHED 2 FREE INTACT FSA'S
P = .40
A
DOUBLE PROX. S.P. EXPOSURE OF FSA'S
P = 1.28723×10^{-5}
FUEL RELEASED
1. 5.2534×10^{-14}
3. 6.1808×10^{-14}
B
NO DOUBLE PROX. S.P. EXPOSURE OF FSA'S
P = .999987
NO FUEL RELEASE
1. 4.0811×10^{-9}
3. 4.8015×10^{-9}

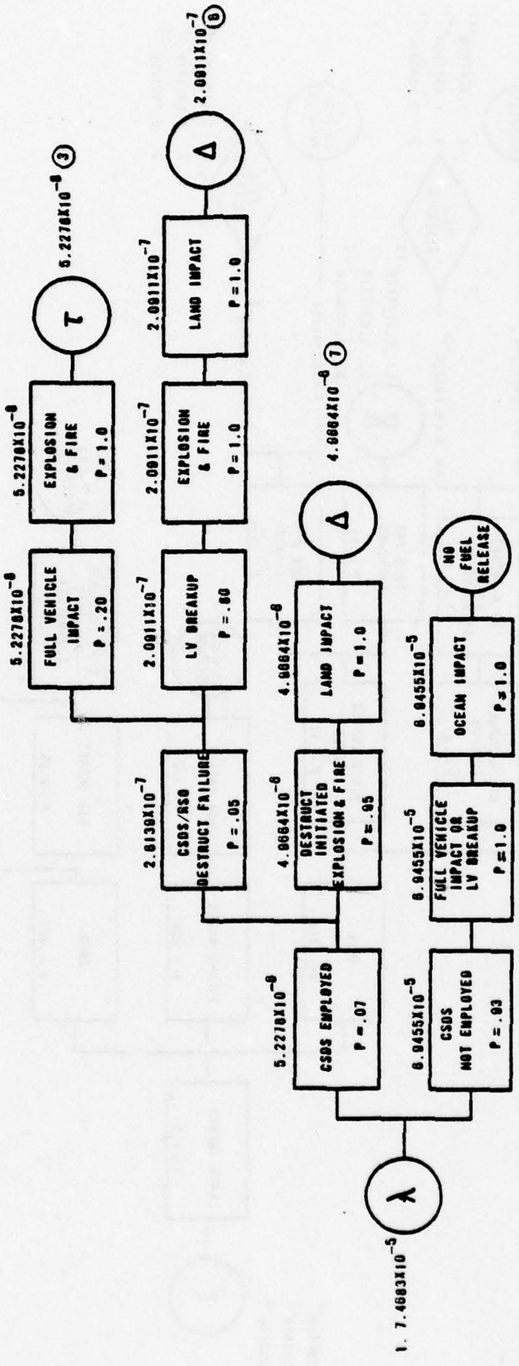

1. 1.1772x10^-8
2. 1.3845x10^-8
ζ
A
DOUBLE PROX.
S.P. EXPOSURE
OF FSA'S
P = 1.28723x10^-5
FUEL
RELEASED
1.5153x10^-13 1.
1.7822x10^-13 3.
B
SINGLE PROX.
S.P. EXPOSURE
OF FSA'S
P = 1.355x10^-3
FUEL
RELEASED
1.5951x10^-11 1.
1.876x10^-11 3.
C
NO S.P. EXPOS.
OF FSA'S
P = .998632
FUEL
RELEASED
1.1756x10^-8 1.
1.3826x10^-8 3.

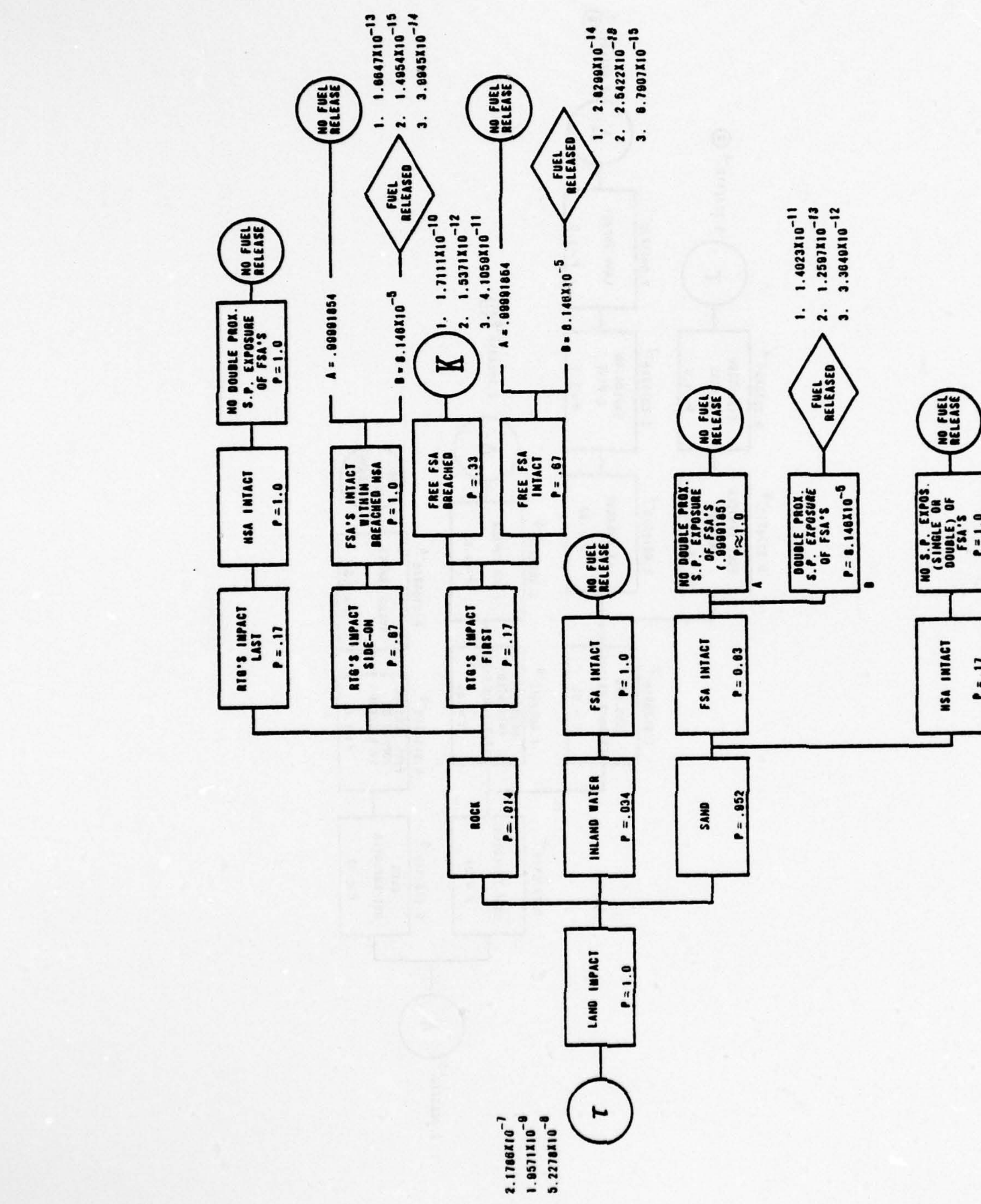

H
1. 0.0
2. 0.0
3. 0.0
4. 2.2603x10^-8
5. 4.473x10^-7
6. 4.0192x10^-9
CONVERTER DAMAGED, HSA INTACT P = .10
B = 1.0
NO FUEL RELEASE
1. 0.0
2. 0.0
3. 0.0
4. 2.2603x10^-9
5. 4.473x10^-8
6. 4.0192x10^-10
CONVERTER DAMAGED, HSA BREACHED, FSA'S INTACT WITHIN P = .10
B = 1.0
NO FUEL RELEASE
1. 0.0
2. 0.0
3. 0.0
4. 2.2603x10^-9
5. 4.473x10^-8
6. 4.0192x10^-10
FREE BREACHED HSA, FSA'S INTACT WITHIN P = .40
A = 1.62924x10^-5
FUEL RELEASED
1. 0.0
2. 0.0
3. 0.0
4. 1.473x10^-13
5. 2.915x10^-12
6. 2.6193x10^-14
B = .9999837
NO FUEL RELEASE
1. 0.0
2. 0.0
3. 0.0
4. 9.0411x10^-9
5. 1.7892x10^-7
6. 1.6077x10^-9
FREE HSA BREACHED, 2 FREE INTACT FSA'S P = .40
A
DOUBLE PROX. S.P. EXPOSURE OF FSA'S P = 1.62924x10^-5
FUEL RELEASED
1. 0.0
2. 0.0
3. 0.0
4. 1.473x10^-13
5. 2.915x10^-12
6. 2.6193x10^-14
B
NO DOUBLE PROX. S.P. EXPOSURE OF FSA'S P = .9999837
NO FUEL RELEASE
1. 0.0
2. 0.0
3. 0.0
4. 9.0411x10^-9
5. 1.7892x10^-7
6. 1.6077x10^-9


DOUBLE PROX. S.P. EXPOSURE OF FSA'S
$P = 1.62924\times10^{-5}$
A
FUEL RELEASED
1. 0
2. 0
3. 0
4. 4.2487×10^{-13}
5. 8.4082×10^{-12}
6. 7.5553×10^{-14}
SINGLE PROX. S.P. EXPOSURE OF FSA'S
$P = 1.715\times10^{-3}$
B
FUEL RELEASED
1. 0
2. 0
3. 0
4. 4.4724×10^{-11}
5. 8.8508×10^{-10}
6. 7.953×10^{-12}
NO S.P. EXPOS OF FSA'S
P = .9982887
C
FUEL RELEASED
1. 0
2. 0
3. 0
4. 2.6033×10^{-8}
5. 5.1519×10^{-7}
6. 4.6293×10^{-9}
Ω
1. 0.0
2. 0.0
3. 0.0
4. 2.6078×10^{-8}
5. 5.1608×10^{-7}
6. 4.6373×10^{-9}

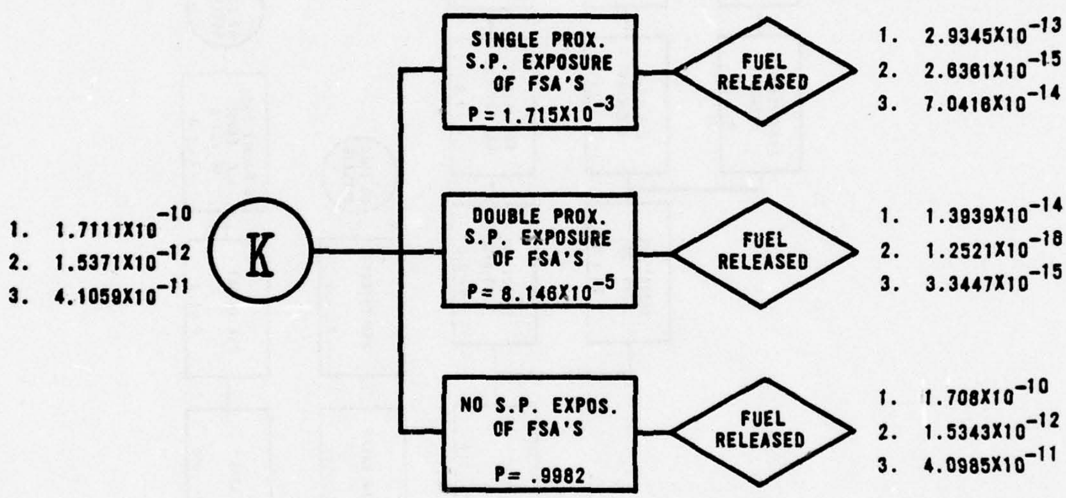
EARLY ASCENT 2, PHASE 2B

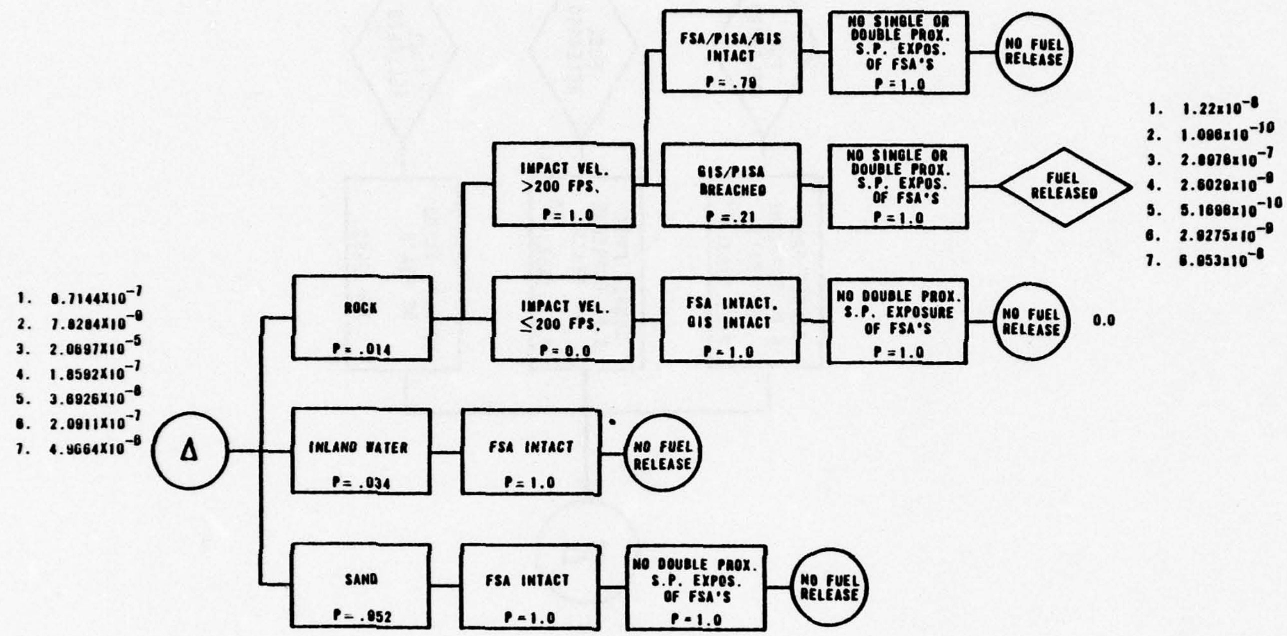



1. 7.4683X10^{-5}
λ
5.2278X10^{-6}
CSDS EMPLOYED
P=.07
6.9455X10^{-5}
CSDS
NOT EMPLOYED
P=.93
2.6139X10^{-7}
CSDS/RSO
DESTRUCT FAILURE
P=.05
4.9664X10^{-6}
DESTRUCT
INITIATED
EXPLOSION & FIRE
P=.95
6.9455X10^{-5}
FULL VEHICLE
IMPACT OR
LV BREAKUP
P=1.0
5.2278X10^{-8}
FULL VEHICLE
IMPACT
P=.20
2.0911X10^{-7}
LV BREAKUP
P=.80
4.9664X10^{-6}
LAND IMPACT
P=1.0
6.9455X10^{-5}
OCEAN IMPACT
P=1.0
NO
FUEL
RELEASE
5.2278X10^{-8}
EXPLOSION
& FIRE
P=1.0
2.0911X10^{-7}
EXPLOSION
& FIRE
P=1.0
2.0911X10^{-7}
LAND IMPACT
P=1.0
τ
5.2278X10^{-8} (3)
Δ
2.0911X10^{-7} (6)
Δ
4.9664X10^{-6} (7)


T
1. 2.1786×10^{-7}
2. 1.9571×10^{-9}
3. 5.2278×10^{-8}
LAND IMPACT P = 1.0
ROCK P = .014
INLAND WATER P = .034
SAND P = .952
RTG'S IMPACT LAST P = .17
RTG'S IMPACT SIDE-ON P = .67
RTG'S IMPACT FIRST P = .17
NSA INTACT P = 1.0
NO DOUBLE PROX. S.P. EXPOSURE OF FSA'S P = 1.0
NO FUEL RELEASE
FSA'S INTACT WITHIN BREACHED NSA P = 1.0
A = .99991854
NO FUEL RELEASE
B = 8.146×10^{-5}
FUEL RELEASED
1. 1.8647×10^{-13}
2. 1.4954×10^{-15}
3. 3.9945×10^{-14}
FREE FSA BREACHED P = .33
K
1. 1.7111×10^{-10}
2. 1.5371×10^{-12}
3. 4.1059×10^{-11}
FREE FSA INTACT P = .67
A = .99991854
NO FUEL RELEASE
B = 8.146×10^{-5}
FUEL RELEASED
1. 2.8299×10^{-14}
2. 2.5422×10^{-16}
3. 6.7907×10^{-15}
FSA INTACT P = 1.0
NO FUEL RELEASE
FSA INTACT P = 0.83
NO DOUBLE PROX. S.P. EXPOSURE OF FSA'S (.9999185) P ≈ 1.0
A
NO FUEL RELEASE
DOUBLE PROX. S.P. EXPOSURE OF FSA'S P = 8.146×10^{-5}
B
FUEL RELEASED
1. 1.4023×10^{-11}
2. 1.2597×10^{-13}
3. 3.3649×10^{-12}
NSA INTACT P = .17
NO S.P. EXPOS. (SINGLE OR DOUBLE) OF FSA'S P = 1.0
NO FUEL RELEASE

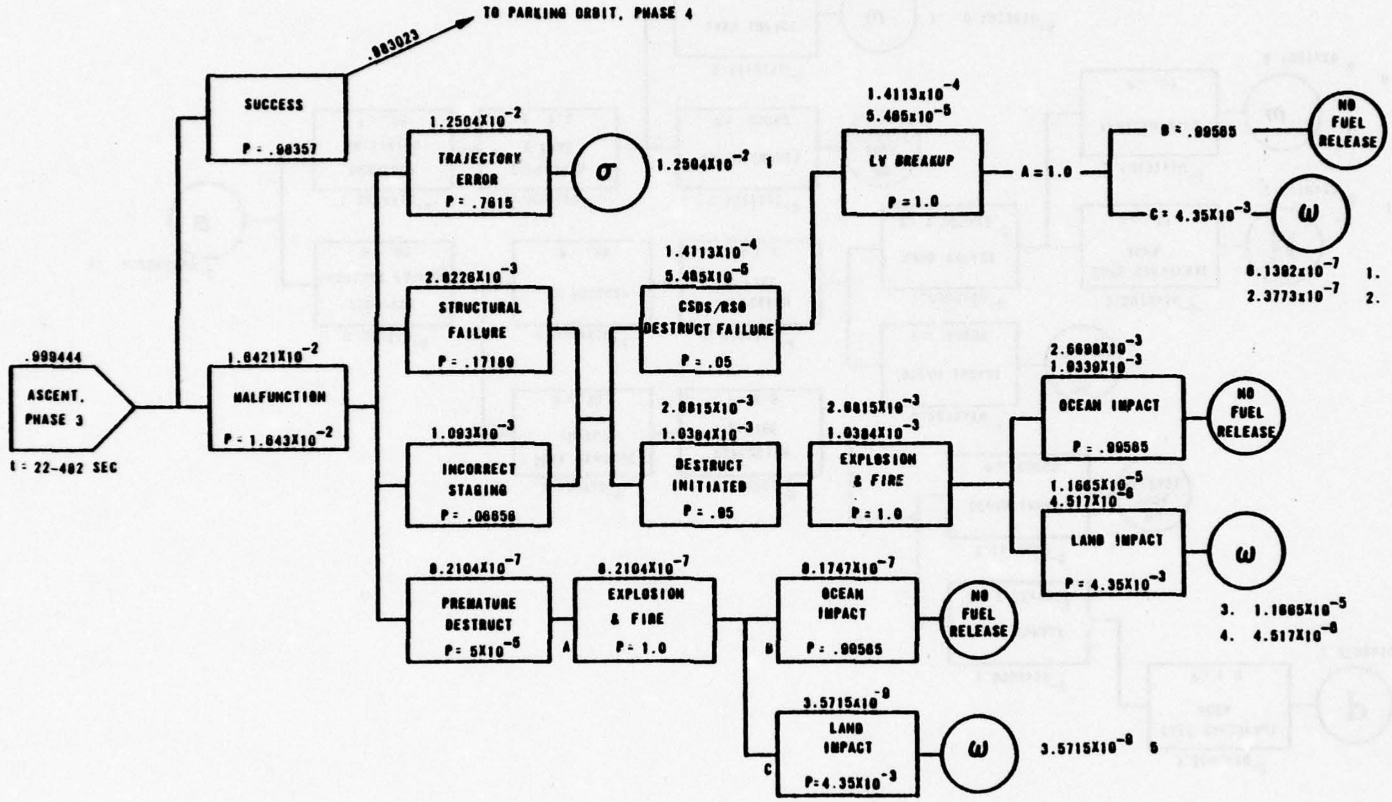
2B-3

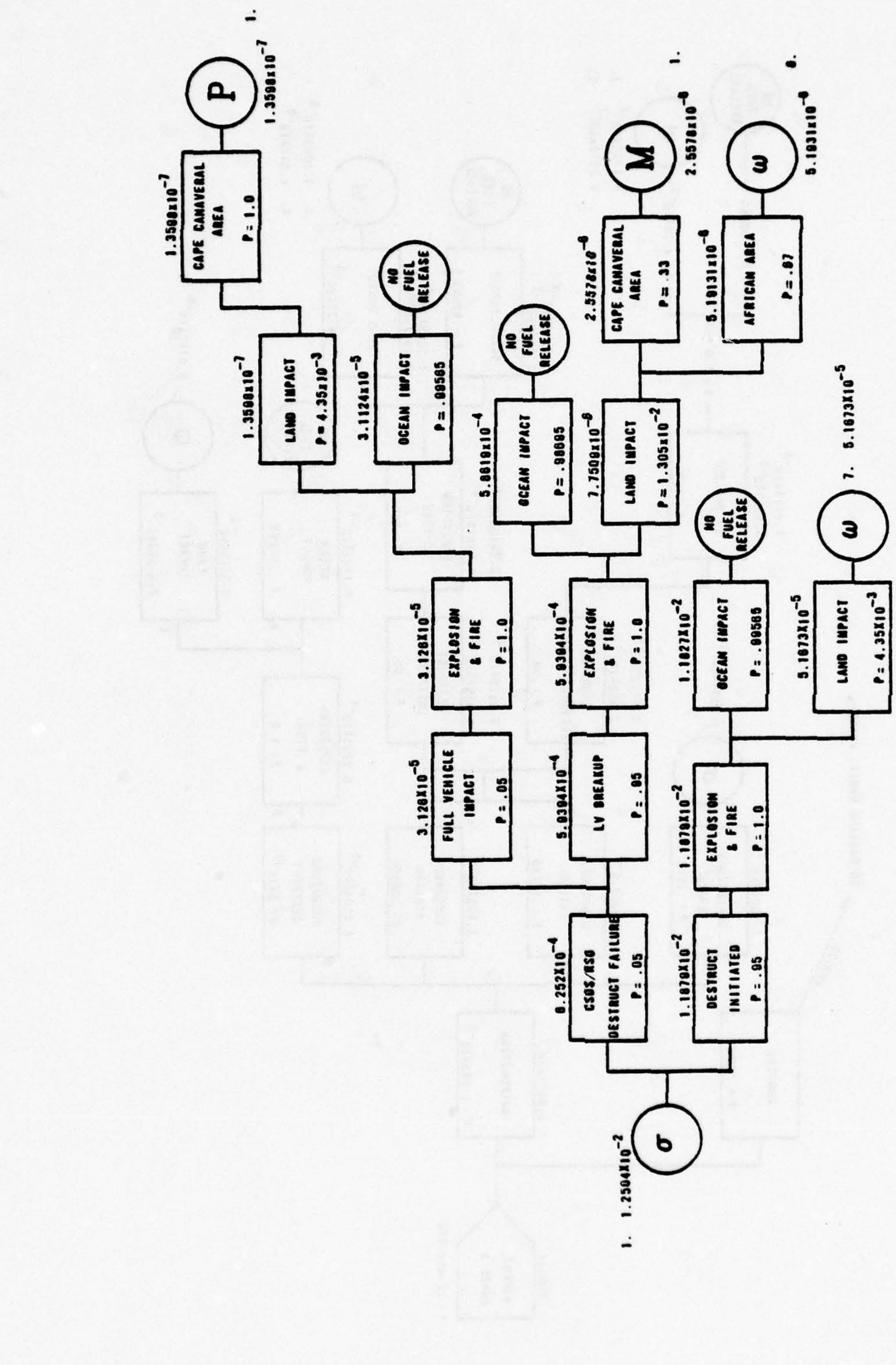

1. 1.7111X10^-10
2. 1.5371X10^-12
3. 4.1059X10^-11
K
SINGLE PROX. S.P. EXPOSURE OF FSA'S
P = 1.715X10^-3
FUEL RELEASED
1. 2.9345X10^-13
2. 2.6361X10^-15
3. 7.0416X10^-14
DOUBLE PROX. S.P. EXPOSURE OF FSA'S
P = 8.146X10^-5
FUEL RELEASED
1. 1.3939X10^-14
2. 1.2521X10^-16
3. 3.3447X10^-15
NO S.P. EXPOS. OF FSA'S
P = .9982
FUEL RELEASED
1. 1.708X10^-10
2. 1.5343X10^-12
3. 4.0985X10^-11

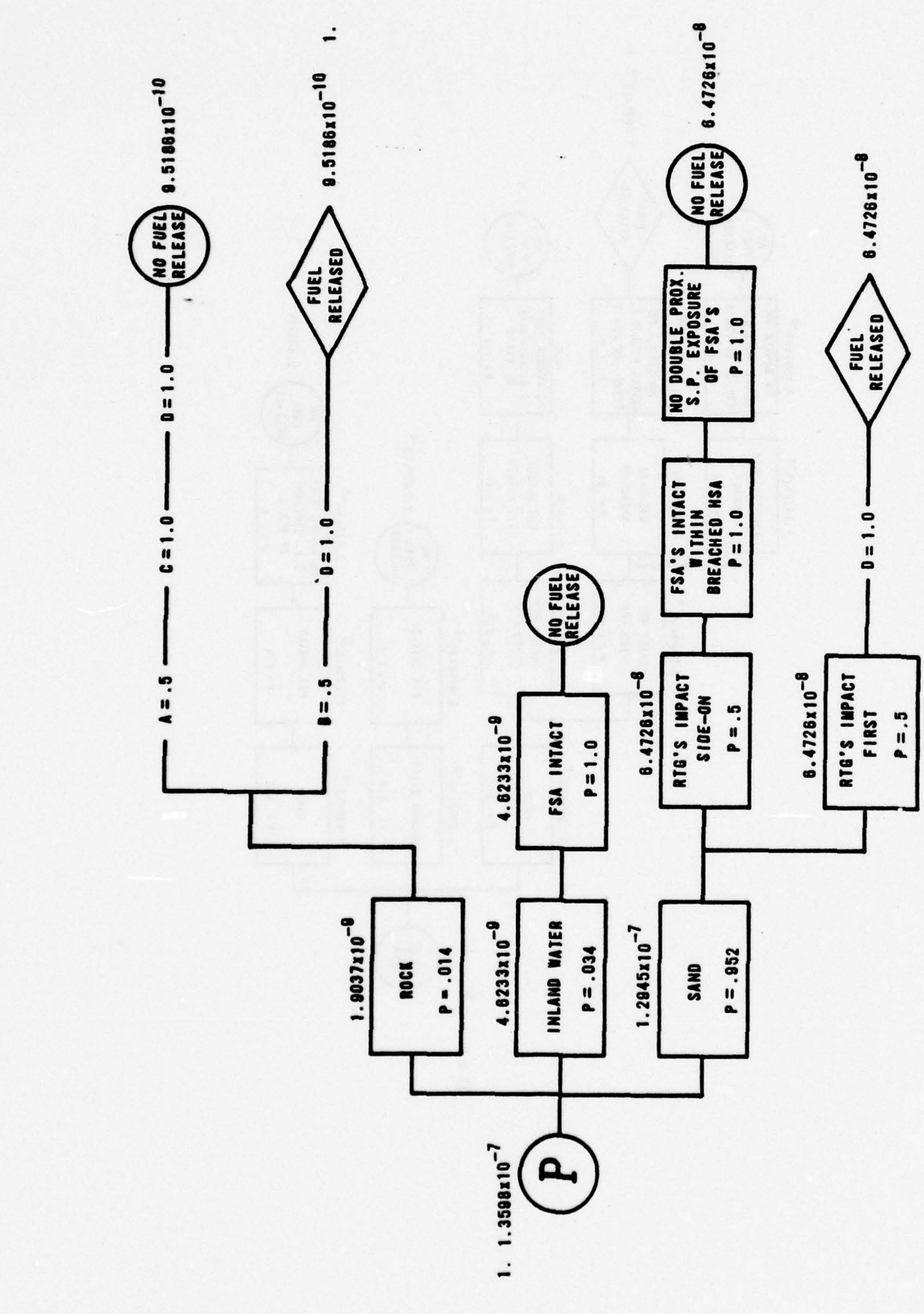


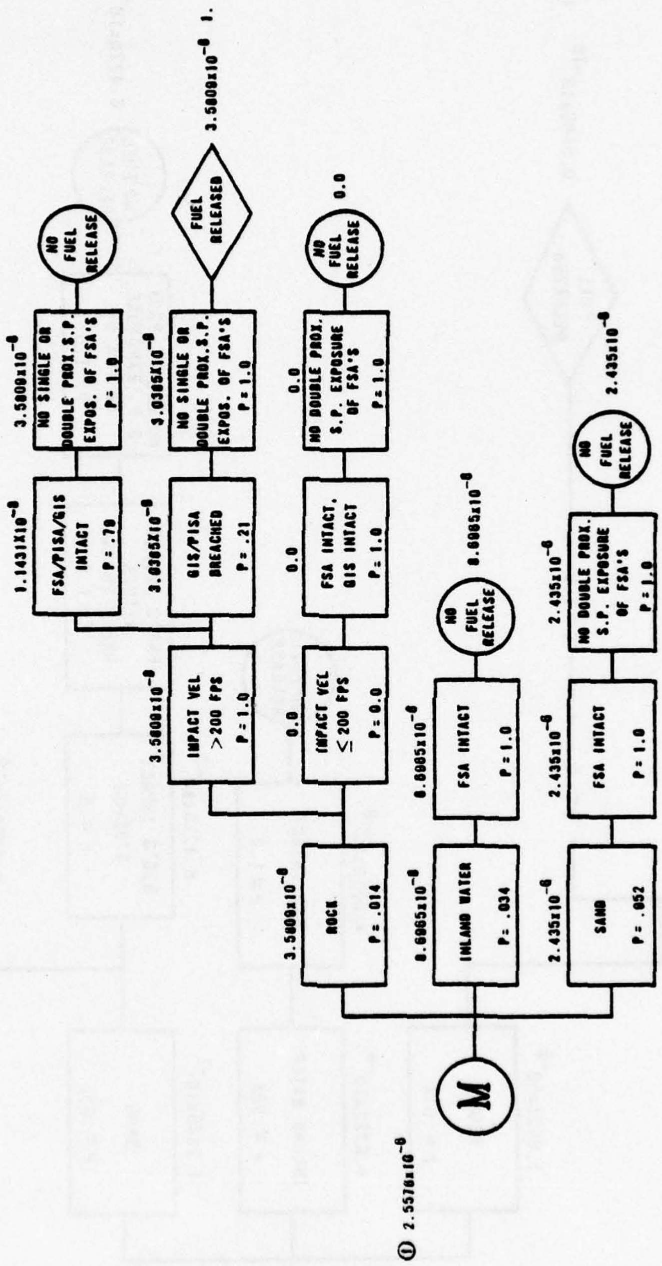
1. 8.7144X10^-7
2. 7.8284X10^-9
3. 2.0697X10^-5
4. 1.8592X10^-7
5. 3.6926X10^-8
6. 2.0911X10^-7
7. 4.9664X10^-8
Δ
ROCK P = .014
INLAND WATER P = .034
SAND P = .952
IMPACT VEL. >200 FPS. P = 1.0
IMPACT VEL. ≤200 FPS. P = 0.0
FSA/PISA/GIS INTACT P = .79
GIS/PISA BREACHED P = .21
FSA INTACT. GIS INTACT P = 1.0
NO SINGLE OR DOUBLE PROX. S.P. EXPOS. OF FSA'S P = 1.0
NO SINGLE OR DOUBLE PROX. S.P. EXPOS. OF FSA'S P = 1.0
NO DOUBLE PROX. S.P. EXPOSURE OF FSA'S P = 1.0
NO FUEL RELEASE
FUEL RELEASED
NO FUEL RELEASE
0.0
FSA INTACT P = 1.0
NO FUEL RELEASE
FSA INTACT P = 1.0
NO DOUBLE PROX. S.P. EXPOS. OF FSA'S P = 1.0
NO FUEL RELEASE
1. 1.22x10^-8
2. 1.096x10^-10
3. 2.8076x10^-7
4. 2.6029x10^-8
5. 5.1696x10^-10
6. 2.8275x10^-9
7. 6.053x10^-8

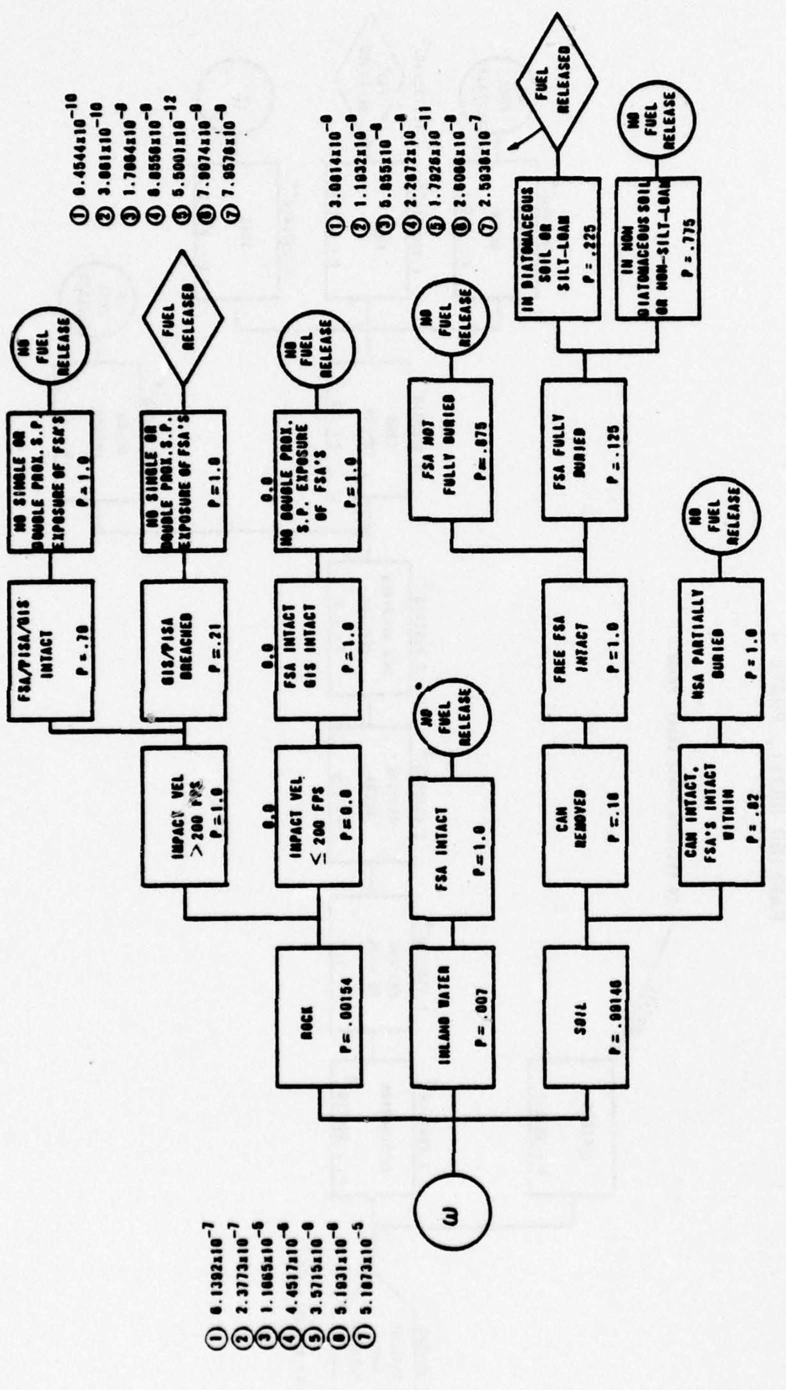
ASCENT, PHASE 3



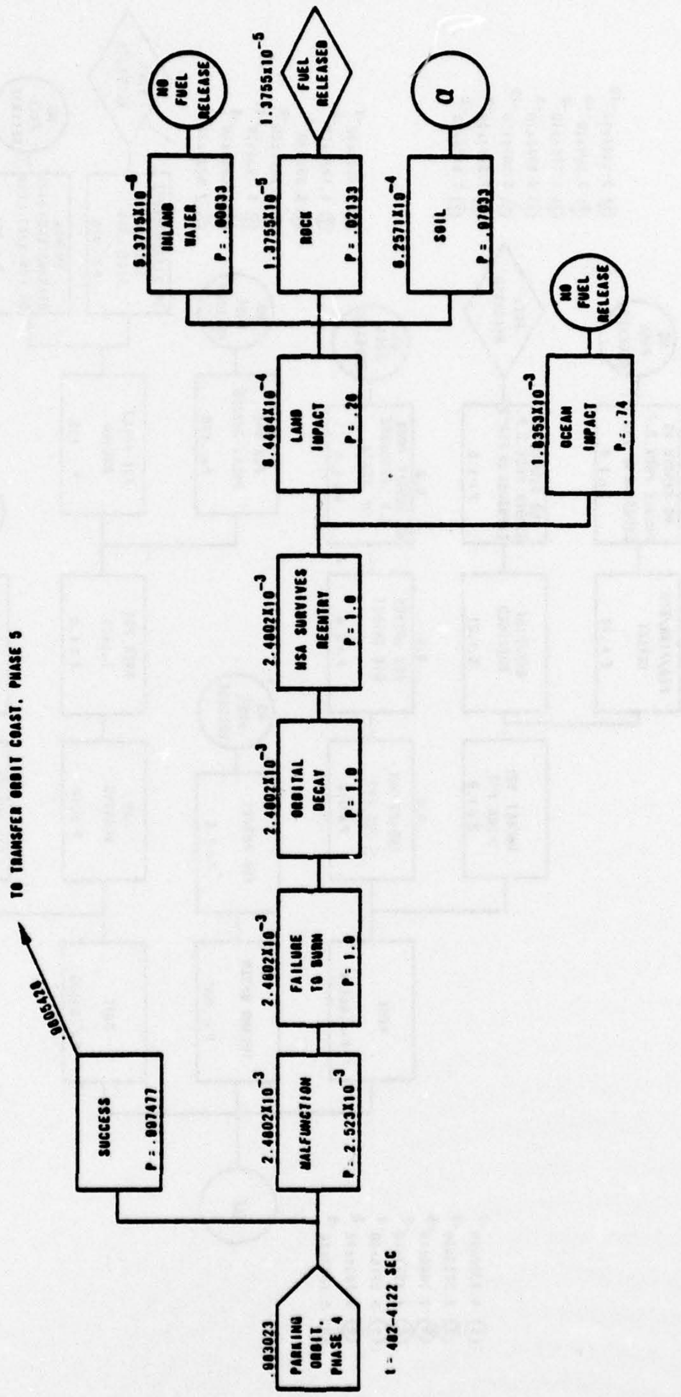

CSDS/MSD DESTRUCT FAILURE P = .05
DESTRUCT INITIATED P = .95
FULL VEHICLE IMPACT P = .05
LV BREAKUP P = .95
EXPLOSION & FIRE P = 1.0
OCEAN IMPACT P = .99565
LAND IMPACT P = 4.35x10^-3
CAPE CANAVERAL AREA P = 1.0
NO FUEL RELEASE
OCEAN IMPACT P = .98695
LAND IMPACT P = 1.305x10^-2
CAPE CANAVERAL AREA P = .33
AFRICAN AREA P = .67

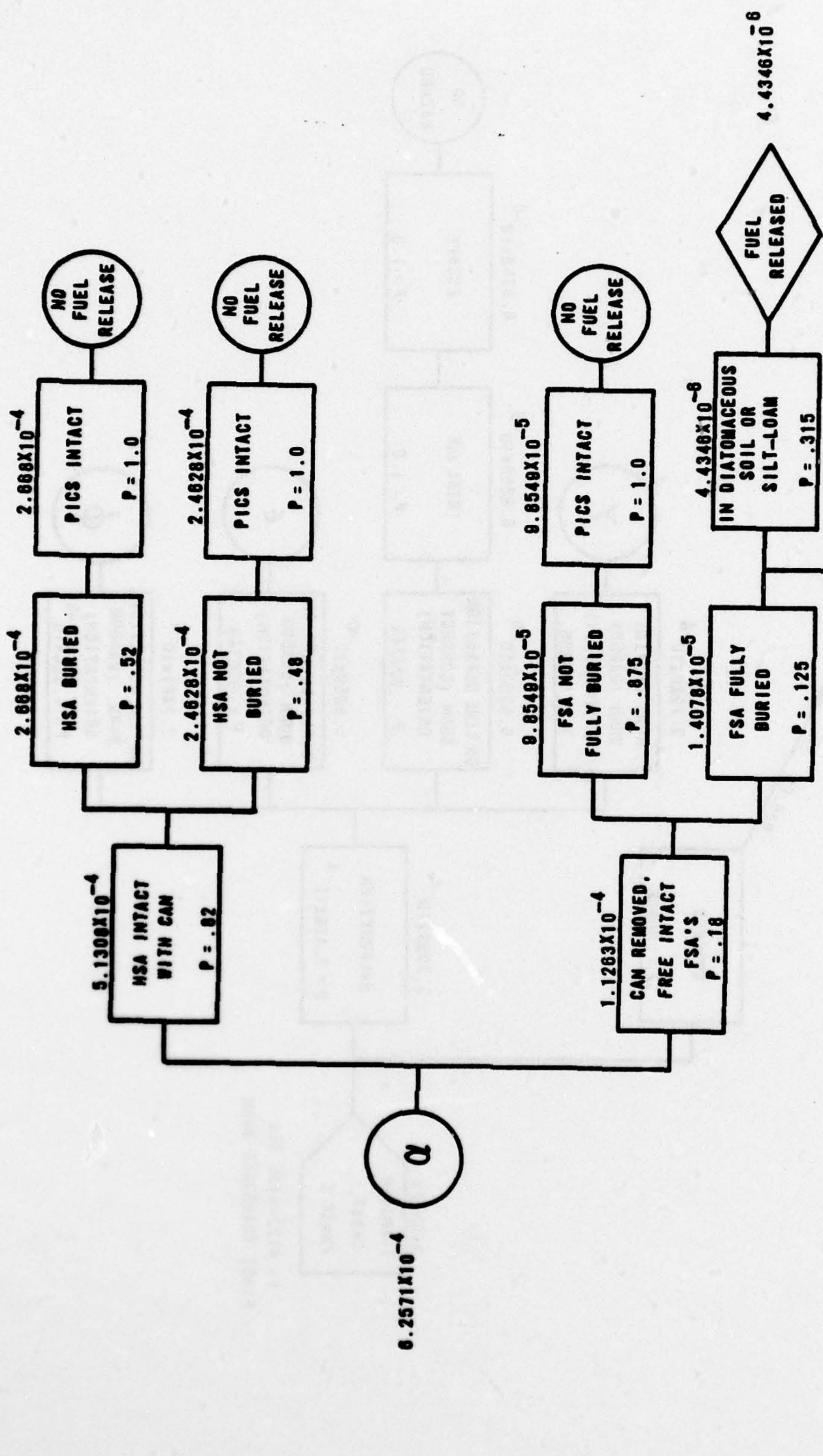

1.
1.3598x10^-7
P
ROCK
P=.014
1.9037x10^-9
INLAND WATER
P=.034
4.6233x10^-9
SAND
P=.952
1.2945x10^-7
A=.5
C=1.0
D=1.0
NO FUEL RELEASE
9.5186x10^-10
B=.5
D=1.0
FUEL RELEASED
9.5186x10^-10
FSA INTACT
P=1.0
4.6233x10^-9
NO FUEL RELEASE
RTG'S IMPACT SIDE-ON
P=.5
6.4726x10^-8
FSA'S INTACT WITHIN BREACHED HSA
P=1.0
NO DOUBLE PROX. S.P. EXPOSURE OF FSA'S
P=1.0
NO FUEL RELEASE
6.4726x10^-8
RTG'S IMPACT FIRST
P=.5
6.4726x10^-8
D=1.0
FUEL RELEASED
6.4726x10^-8
1.


① 2.5578x10^-8
M
3.5800x10^-8
ROCK
P = .014
3.5800x10^-8
IMPACT VEL >200 FPS
P = 1.0
1.1431X10^-8
FSA/PISA/GIS INTACT
P = .79
3.5800x10^-8
NO SINGLE OR DOUBLE PROX.S.P. EXPOS. OF FSA'S
P = 1.0
NO FUEL RELEASE
3.0305X10^-8
GIS/PISA BREACHED
P = .21
3.0305X10^-8
NO SINGLE OR DOUBLE PROX.S.P. EXPOS. OF FSA'S
P = 1.0
FUEL RELEASED
3.5800x10^-8 1.
0.0
IMPACT VEL ≤200 FPS
P = 0.0
0.0
FSA INTACT, GIS INTACT
P = 1.0
0.0
NO DOUBLE PROX. S.P. EXPOSURE OF FSA'S
P = 1.0
NO FUEL RELEASE
0.0
8.6965x10^-8
INLAND WATER
P = .034
8.6965x10^-8
FSA INTACT
P = 1.0
NO FUEL RELEASE
8.6965x10^-8
2.435x10^-8
SAND
P = .052
2.435x10^-8
FSA INTACT
P = 1.0
2.435x10^-8
NO DOUBLE PROX. S.P. EXPOSURE OF FSA'S
P = 1.0
NO FUEL RELEASE
2.435x10^-8

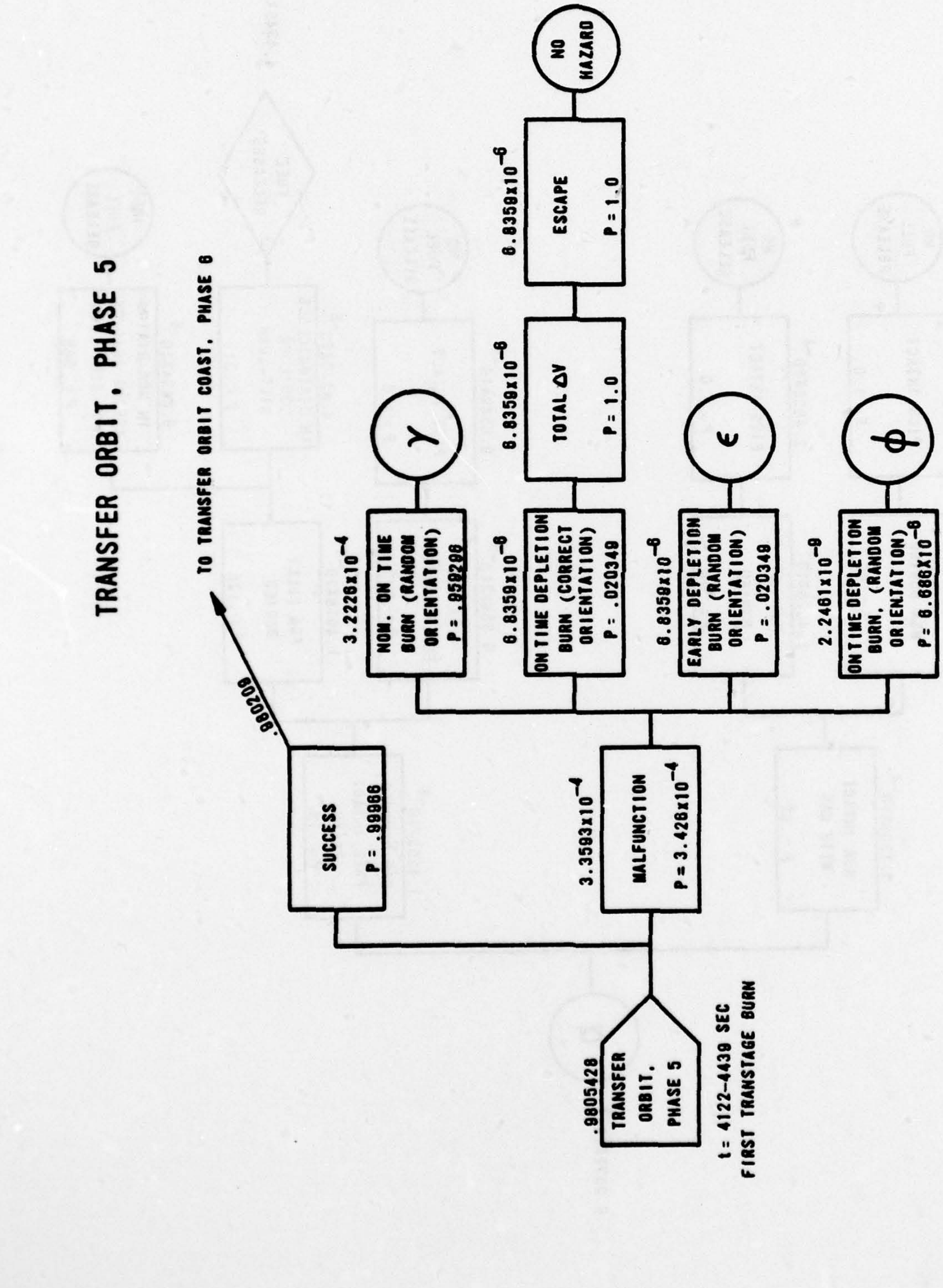

ω
ROCK P= .00154
INLAND WATER P= .007
SOIL P= .00146
IMPACT VEL > 200 FPS P=1.0
IMPACT VEL ≤ 200 FPS P=0.0
0.0
FSA INTACT P=1.0
NO FUEL RELEASE
CAN REMOVED P=.10
CAN INTACT, FSA'S INTACT WITHIN P= .02
FSA/PISA/GIS INTACT P=.79
GIS/PISA BREACHED P=.21
FSA INTACT GIS INTACT P=1.0
FREE FSA INTACT P=1.0
NSA PARTIALLY BURIED P=1.0
NO SINGLE OR DOUBLE PROX. S.P. EXPOSURE OF FSA'S P=1.0
NO DOUBLE PROX. S.P. EXPOSURE OF FSA'S P=1.0
FSA NOT FULLY BURIED P=.875
FSA FULLY BURIED P=.125
IN DIATOMACEOUS SOIL OR SILT-LOAM P=.225
IN NON DIATOMACEOUS SOIL OR NON-SILT-LOAM P=.775
FUEL RELEASED
NO FUEL RELEASE
① 6.1392x10^-7
② 2.3773x10^-7
③ 1.1665x10^-5
④ 4.4517x10^-6
⑤ 3.5715x10^-8
⑥ 5.1931x10^-8
⑦ 5.1873x10^-5
① 6.4544x10^-10
② 3.061x10^-10
③ 1.7064x10^-8
④ 6.8556x10^-8
⑤ 5.5001x10^-12
⑥ 7.0074x10^-8
⑦ 7.6576x10^-8
① 3.0014x10^-8
② 1.1032x10^-8
③ 5.855x10^-8
④ 2.2072x10^-8
⑤ 1.7926x10^-11
⑥ 2.6066x10^-8
⑦ 2.5036x10^-7

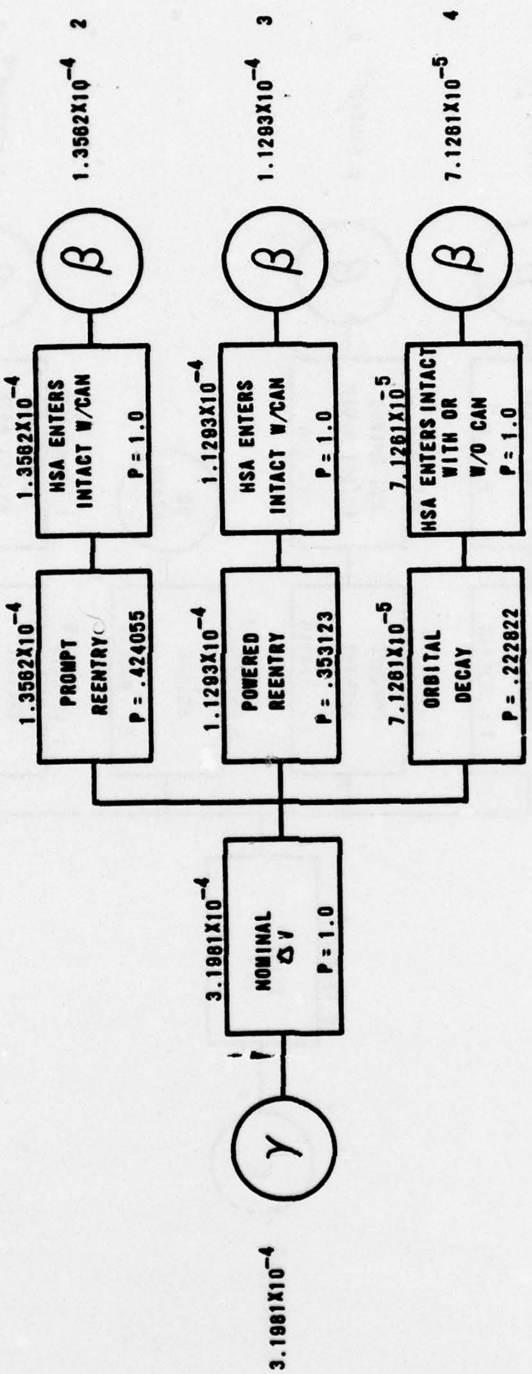
PARKING ORBIT, PHASE 4

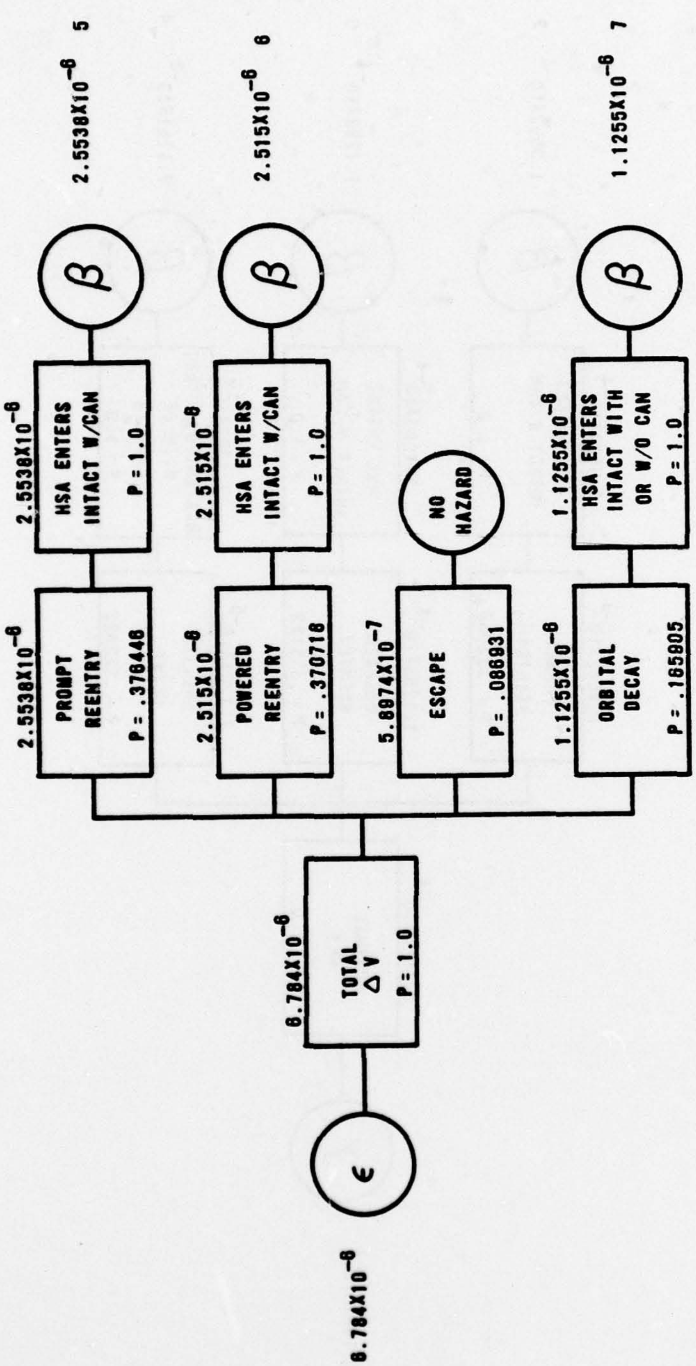


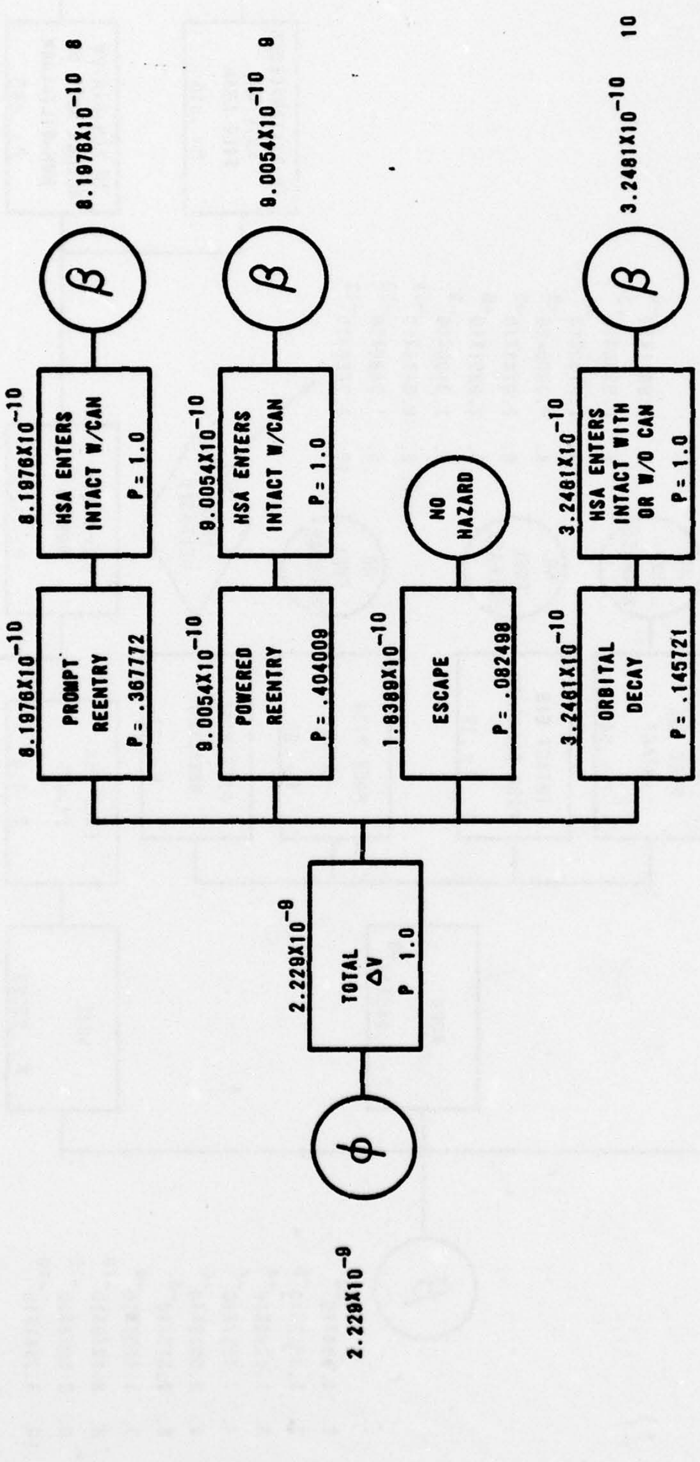

6.2571X10^-4
α
5.1308X10^-4
HSA INTACT WITH CAN
P = .82
2.668X10^-4
HSA BURIED
P = .52
2.668X10^-4
PICS INTACT
P = 1.0
NO FUEL RELEASE
2.4628X10^-4
HSA NOT BURIED
P = .48
2.4628X10^-4
PICS INTACT
P = 1.0
NO FUEL RELEASE
1.1263X10^-4
CAN REMOVED, FREE INTACT FSA'S
P = .18
9.8549X10^-5
FSA NOT FULLY BURIED
P = .875
9.8549X10^-5
PICS INTACT
P = 1.0
NO FUEL RELEASE
1.4078X10^-5
FSA FULLY BURIED
P = .125
4.4346X10^-6
IN DIATOMACEOUS SOIL OR SILT-LOAM
P = .315
FUEL RELEASED
4.4346X10^-6
9.6434X10^-6
IN NON-DIATOMACEOUS SOIL OR NON-SILT-LOAM
P = .685
NO FUEL RELEASE

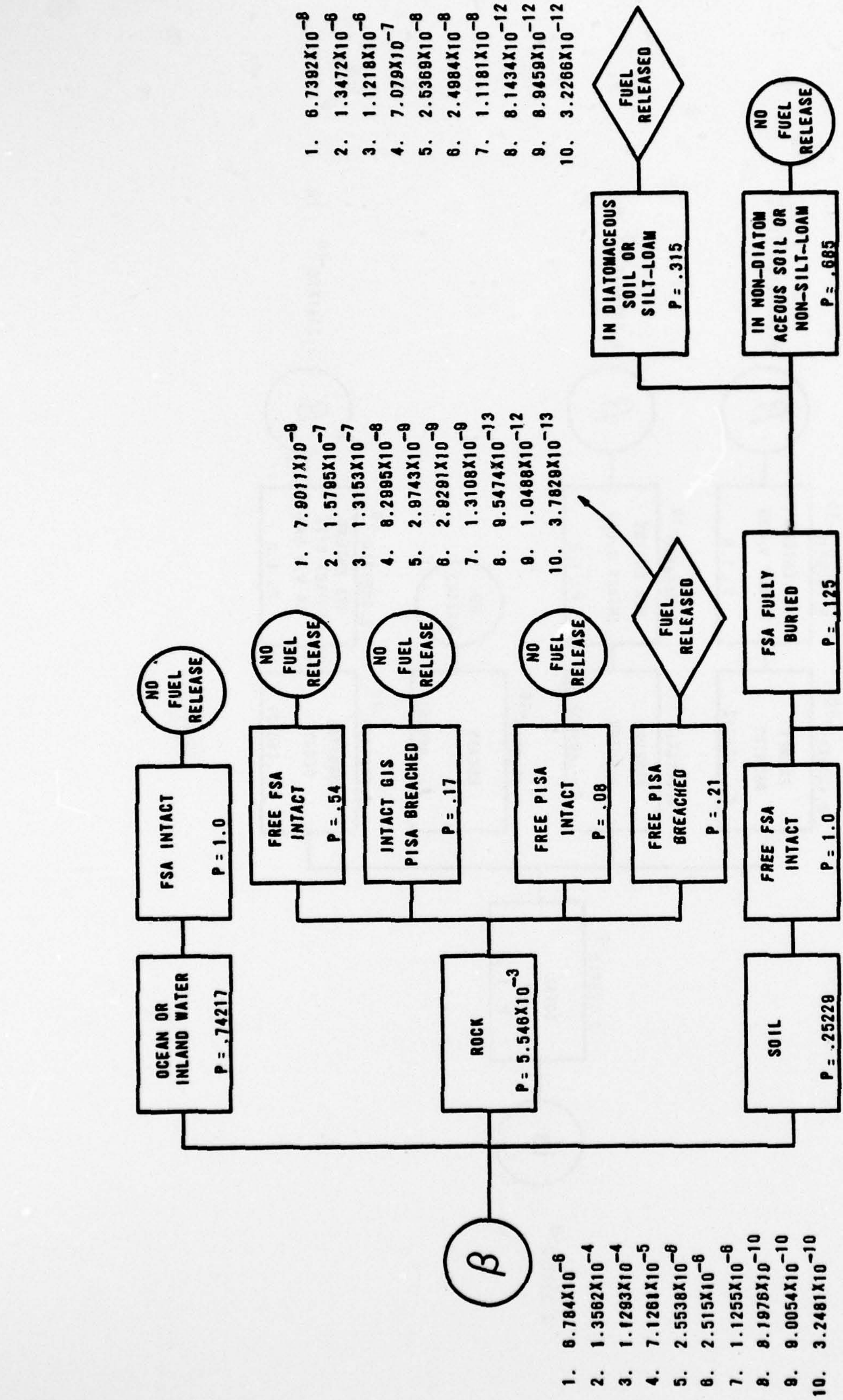
TRANSFER ORBIT, PHASE 5



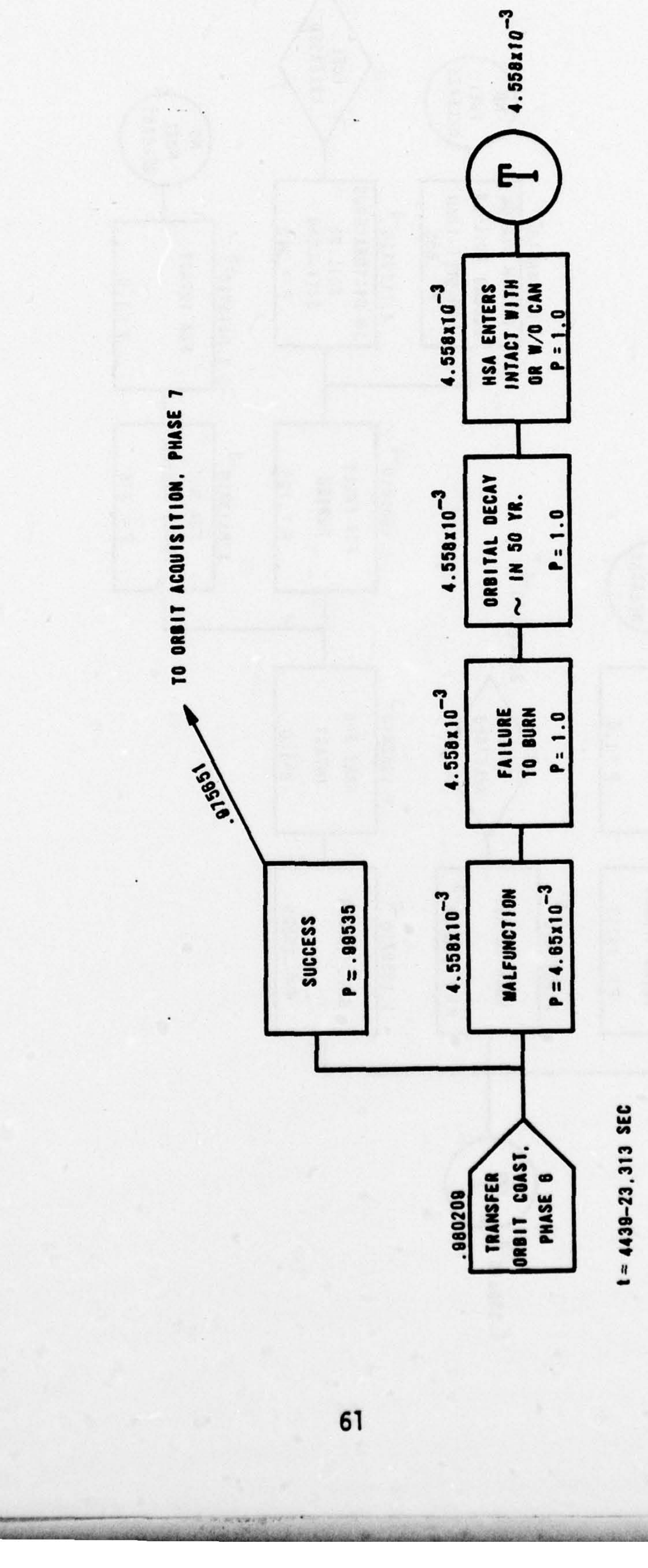

3.1981X10^-4
γ
3.1981X10^-4
NOMINAL
ΔV
P = 1.0
1.3562X10^-4
PROMPT
REENTRY
P = .424055
1.1293X10^-4
POWERED
REENTRY
P = .353123
7.1281X10^-5
ORBITAL
DECAY
P = .222822
1.3562X10^-4
HSA ENTERS
INTACT W/CAN
P = 1.0
1.1293X10^-4
HSA ENTERS
INTACT W/CAN
P = 1.0
7.1281X10^-5
HSA ENTERS INTACT
WITH OR
W/O CAN
P = 1.0
β
β
β
1.3562X10^-4 2
1.1293X10^-4 3
7.1281X10^-5 4

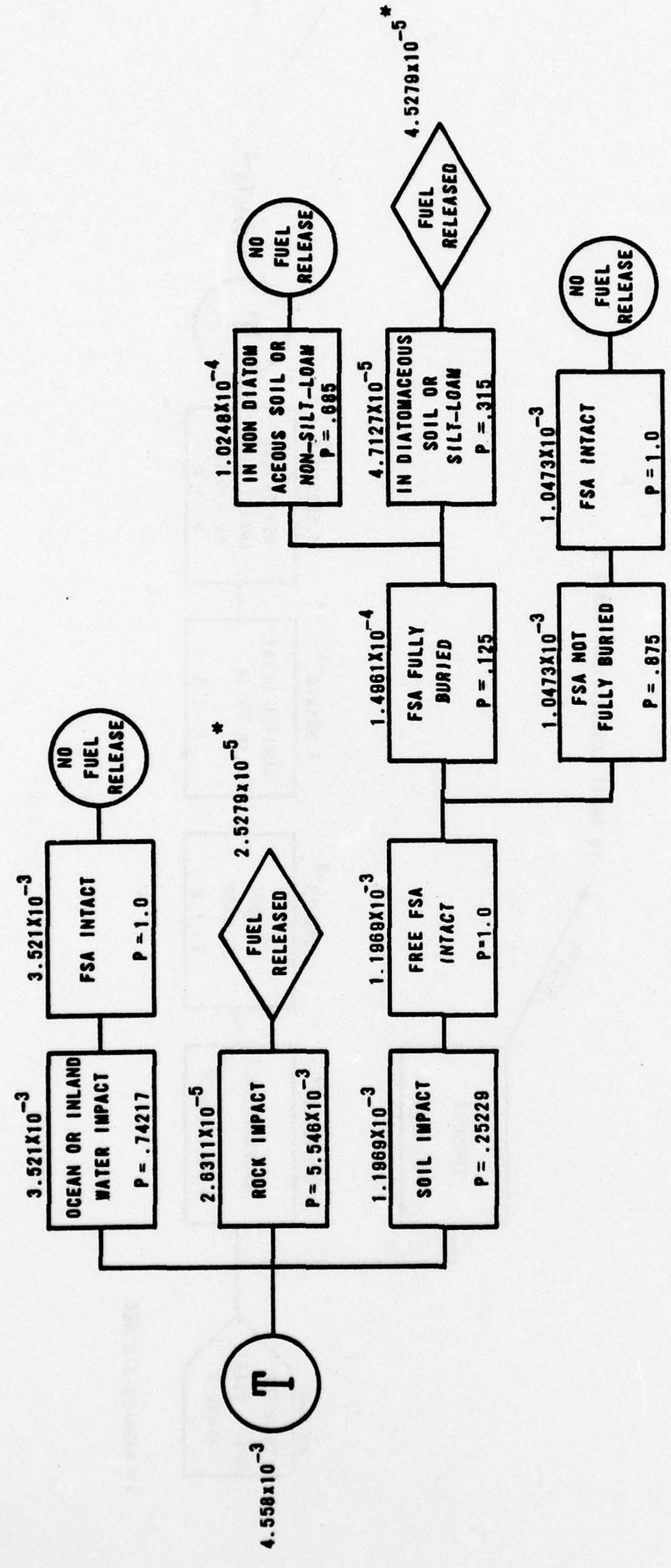

6.784X10^-6
ε
6.784X10^-6
TOTAL ΔV
P = 1.0
2.5538X10^-6
PROMPT REENTRY
P = .376446
2.515X10^-6
POWERED REENTRY
P = .370718
5.8974X10^-7
ESCAPE
P = .086931
1.1255X10^-6
ORBITAL DECAY
P = .165905
2.5538X10^-6
HSA ENTERS INTACT W/CAN
P = 1.0
2.515X10^-6
HSA ENTERS INTACT W/CAN
P = 1.0
NO HAZARD
1.1255X10^-6
HSA ENTERS INTACT WITH OR W/O CAN
P = 1.0
β
β
β
2.5538X10^-6 5
2.515X10^-6 6
1.1255X10^-6 7


2.229X10^-9
φ
TOTAL ΔV P 1.0
2.229X10^-9
PROMPT REENTRY P = .367772
8.1976X10^-10
HSA ENTERS INTACT W/CAN P = 1.0
8.1976X10^-10
β
8.1976X10^-10 8
POWERED REENTRY P = .404009
9.0054X10^-10
HSA ENTERS INTACT W/CAN P = 1.0
9.0054X10^-10
β
9.0054X10^-10 9
ESCAPE P = .082498
1.8389X10^-10
NO HAZARD
ORBITAL DECAY P = .145721
3.2481X10^-10
HSA ENTERS INTACT WITH OR W/O CAN P = 1.0
3.2481X10^-10
β
3.2481X10^-10 10


β
1. 6.784×10^{-6}
2. 1.3582×10^{-4}
3. 1.1293×10^{-4}
4. 7.1281×10^{-5}
5. 2.5538×10^{-6}
6. 2.515×10^{-6}
7. 1.1255×10^{-6}
8. 8.1976×10^{-10}
9. 9.0054×10^{-10}
10. 3.2481×10^{-10}
OCEAN OR INLAND WATER P = .74217
FSA INTACT P = 1.0
NO FUEL RELEASE
ROCK P = 5.546×10^{-3}
FREE FSA INTACT P = .54
NO FUEL RELEASE
INTACT GIS PISA BREACHED P = .17
NO FUEL RELEASE
FREE PISA INTACT P = .08
NO FUEL RELEASE
FREE PISA BREACHED P = .21
FUEL RELEASED
1. 7.9011×10^{-9}
2. 1.5795×10^{-7}
3. 1.3153×10^{-7}
4. 8.2895×10^{-8}
5. 2.9743×10^{-9}
6. 2.9291×10^{-9}
7. 1.3108×10^{-9}
8. 9.5474×10^{-13}
9. 1.0488×10^{-12}
10. 3.7828×10^{-13}
SOIL P = .25229
FREE FSA INTACT P = 1.0
FSA FULLY BURIED P = .125
IN DIATOMACEOUS SOIL OR SILT-LOAM P = .315
FUEL RELEASED
1. 6.7392×10^{-8}
2. 1.3472×10^{-6}
3. 1.1218×10^{-6}
4. 7.079×10^{-7}
5. 2.5369×10^{-8}
6. 2.4984×10^{-8}
7. 1.1181×10^{-8}
8. 8.1434×10^{-12}
9. 8.9459×10^{-12}
10. 3.2266×10^{-12}
IN NON-DIATOMACEOUS SOIL OR NON-SILT-LOAM P = .685
NO FUEL RELEASE
FSA NOT FULLY BURIED P = .875
FSA INTACT P = 1.0
NO FUEL RELEASE

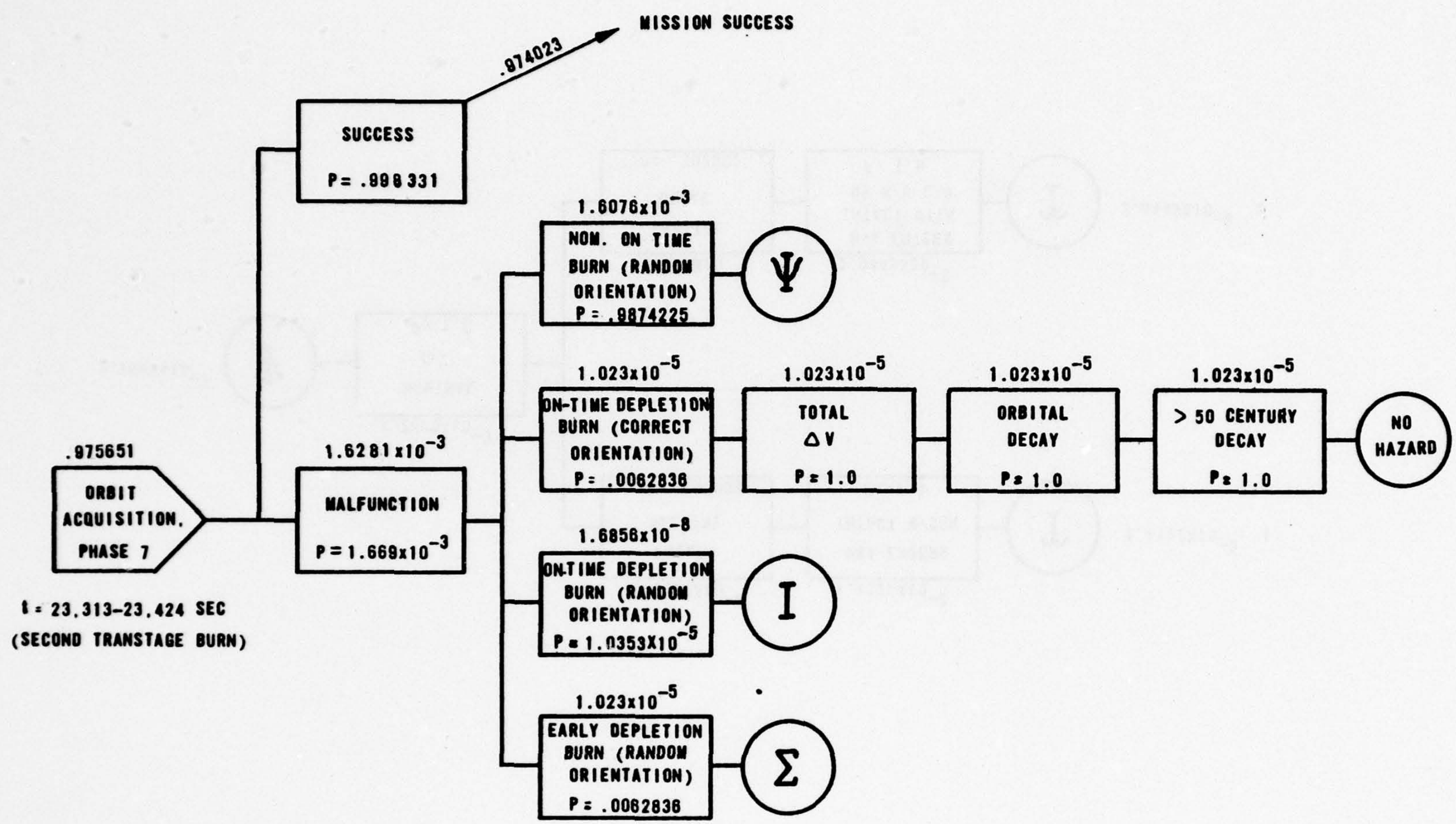
TRANSFER ORBIT COAST, PHASE 6

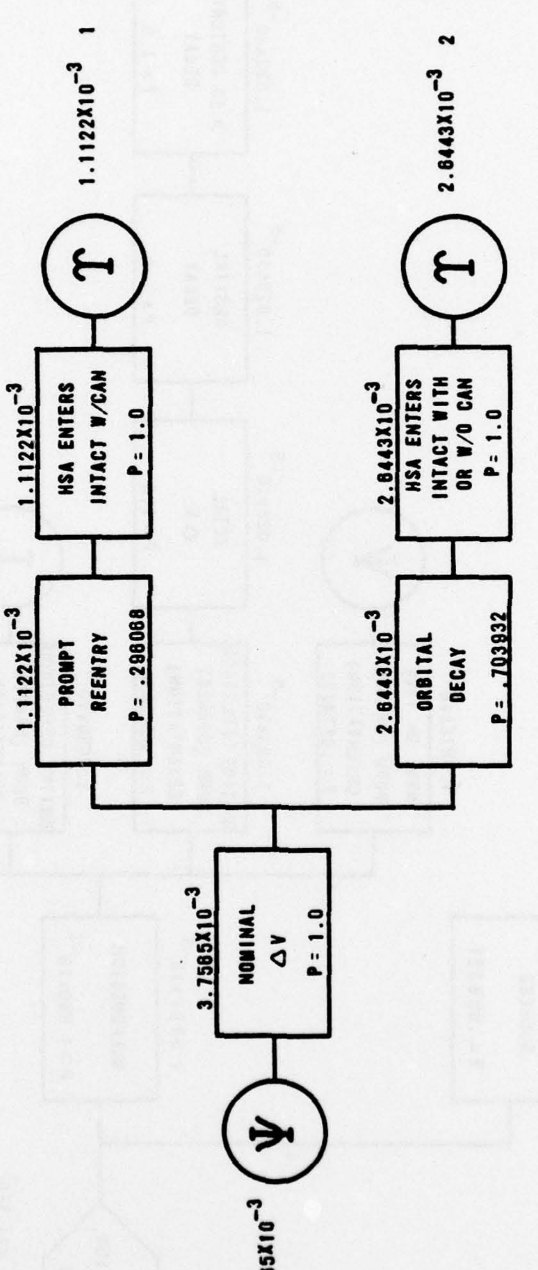


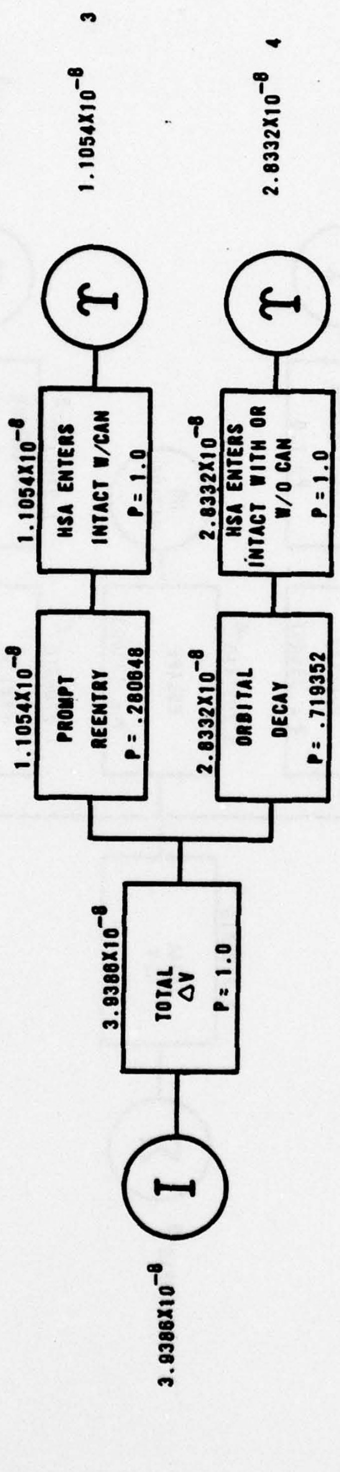


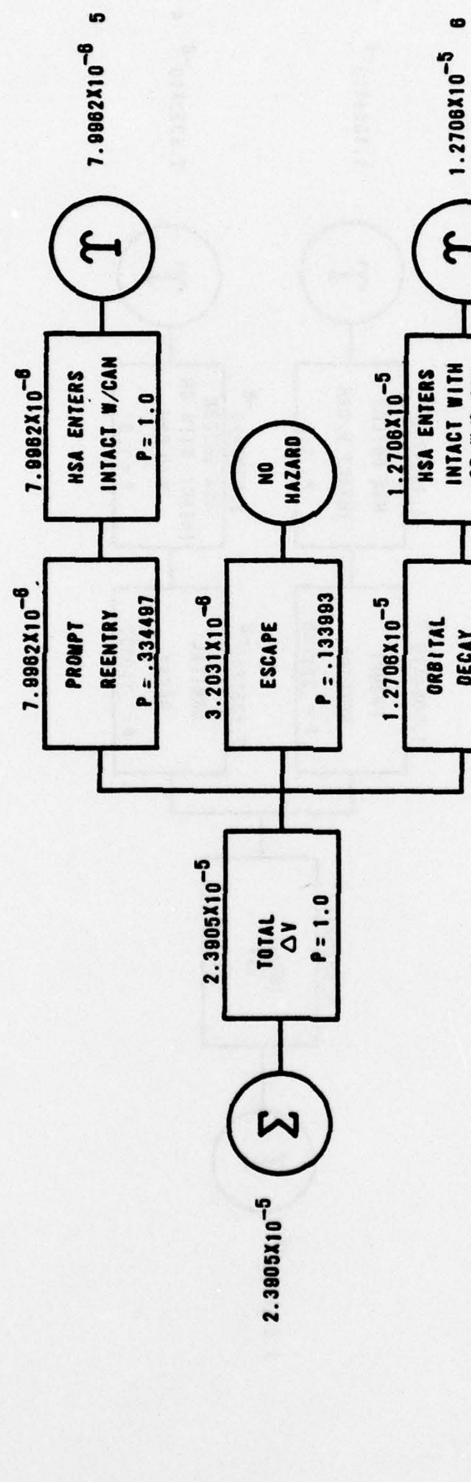
* NO PROMPT SOURCE TERM

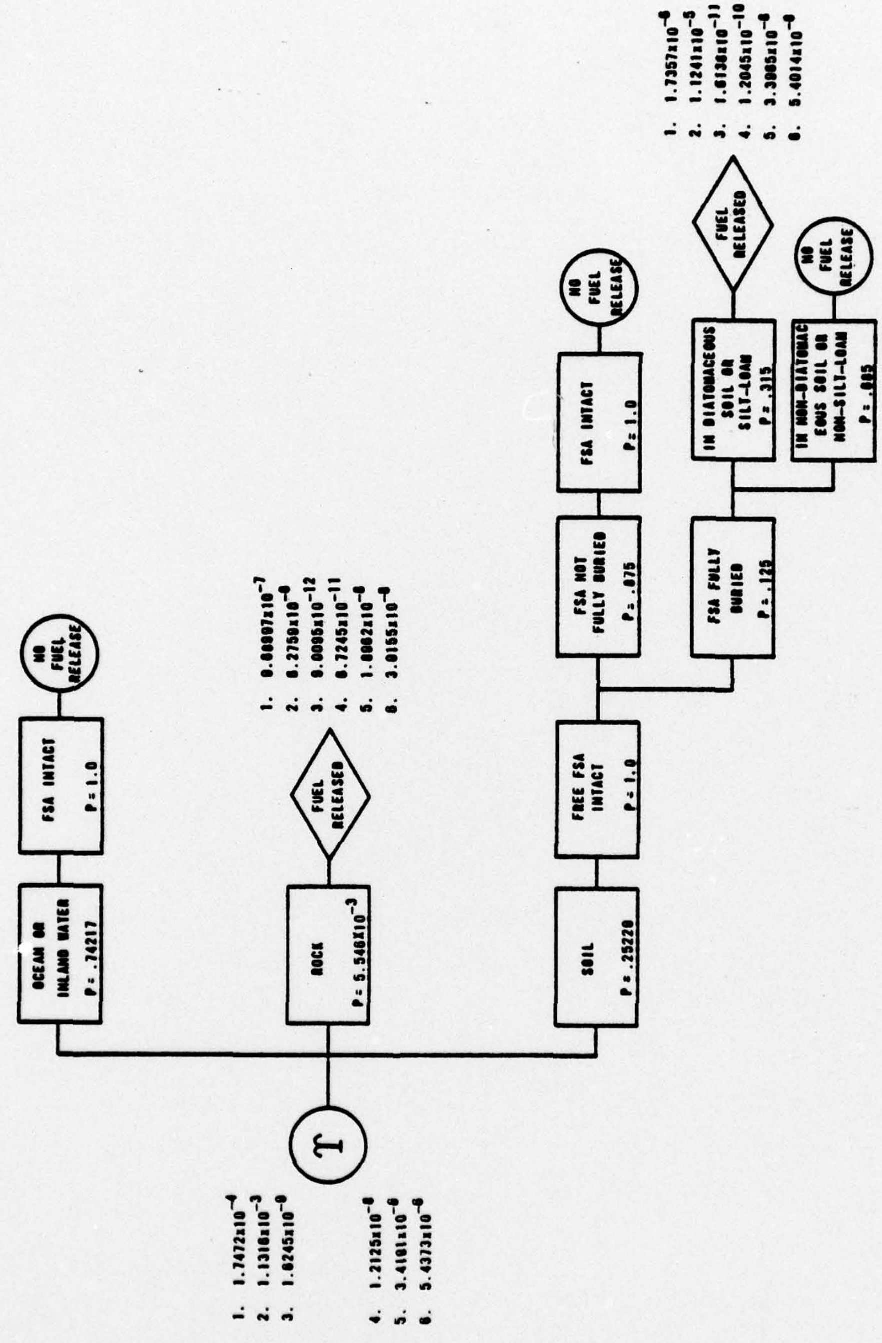
ORBIT ACQUISITION, PHASE 7




3.7585X10^-3
3.7585X10^-3
NOMINAL
ΔV
P = 1.0
1.1122X10^-3
PROMPT
REENTRY
P = .296068
1.1122X10^-3
HSA ENTERS
INTACT W/CAN
P = 1.0
1.1122X10^-3 1
2.6443X10^-3
ORBITAL
DECAY
P = .703932
2.6443X10^-3
HSA ENTERS
INTACT WITH
OR W/O CAN
P = 1.0
2.6443X10^-3 2


3.9386X10-8
I
TOTAL
ΔV
P = 1.0
3.9386X10-8
PROMPT
REENTRY
P = .280648
1.1054X10-8
ORBITAL
DECAY
P = .719352
2.8332X10-8
HSA ENTERS
INTACT W/CAN
P = 1.0
1.1054X10-8
HSA ENTERS
INTACT WITH OR
W/O CAN
P = 1.0
2.8332X10-8
T
1.1054X10-8 3
T
2.8332X10-8 4


2.3905X10^-5
Σ
2.3905X10^-5
TOTAL ΔV P = 1.0
7.9962X10^-6
PROMPT REENTRY P = .334497
3.2031X10^-6
ESCAPE P = .133993
1.2706X10^-5
ORBITAL DECAY P = .53151
7.9962X10^-6
HSA ENTERS INTACT W/CAN P = 1.0
NO HAZARD
1.2706X10^-5
HSA ENTERS INTACT WITH OR W/O CAN P = 1.0
7.9962X10^-6 5
1.2706X10^-5 6


1. 1.7472x10^-4
2. 1.1316x10^-3
3. 1.6245x10^-8
4. 1.2125x10^-8
5. 3.4181x10^-6
6. 5.4373x10^-6
T
OCEAN OR INLAND WATER P = .74217
FSA INTACT P = 1.0
NO FUEL RELEASE
ROCK P = 5.546X10^-3
FUEL RELEASED
1. 9.06997x10^-7
2. 6.2759x10^-8
3. 9.0095x10^-12
4. 6.7245x10^-11
5. 1.0962x10^-8
6. 3.0155x10^-8
SOIL P = .25220
FREE FSA INTACT P = 1.0
FSA NOT FULLY BURIED P = .875
FSA INTACT P = 1.0
NO FUEL RELEASE
FSA FULLY BURIED P = .125
IN DIATOMACEOUS SOIL OR SILT-LOAM P = .315
FUEL RELEASED
1. 1.7357x10^-6
2. 1.1241x10^-5
3. 1.6136x10^-11
4. 1.2045x10^-10
5. 3.3865x10^-8
6. 5.4014x10^-8
IN NON-DIATOMACEOUS SOIL OR NON-SILT-LOAM P = .685
NO FUEL RELEASE